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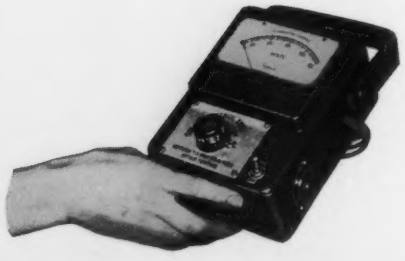

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Electrical REVIEW

THE COVER

The bursting of milky quartz in A-C Research Laboratories' twin pendulum impact tester supplies engineers with impact energy information.

Research studies into comminution of rock provide work index values, basic factors in the design of today's high capacity crushers, and data for the selection of related electrical drive equipment.

Allis-Chalmers Staff Photo by Clarence Hansey

Allis-Chalmers

ELECTRICAL REVIEW

Vol. XXIV No. 1

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Shipping today's large turbine generator equipment

CLEARANCE AND WEIGHT LIMITS required shipping a new fully supercharged, 220-mva generator stator to Virginia Electric & Power Company over eight railroads and through eight states. **(FIGURE 1)**

by C. J. KRAUS
Traffic Department

and

S. R. LAWRENCE
Steam Turbine Department
Allis-Chalmers Mfg. Co.

Growing electric power demands are better served by the larger, more efficient generating units. Shipping the larger equipment results in traffic problems that are being solved by close cooperation between carriers and shippers.

SHIPPING CLEARANCES are challenging factors in the design of large steam turbine-generating units. In the early stages of design of new units, transportation specialists are often consulted to determine the maximum permissible weights and dimensions that can be shipped on carriers' systems to insure proper routing and delivery. The route of every train carrying an unusually large and heavy load generally requires long investigation and planning. Desirability of keeping unit sizes within existing shipping clearances is a factor in the design of the larger capacity generating equipment required by increasing loads.

Steam turbine manufacturers have increased the ratings of many components while maintaining, and even reducing, their physical size. The kilowatt output per foot of a modern steam turbine is as much as four times that of the equivalent rating of 20 years ago. Higher steam pressures and conductor cooling of both the generator rotor and stator have resulted in up to a 400 percent increase in large steam turbine-generator unit capacities with only a 21 percent increase in physical size. Fully-supercharged generators rated 125 mw and larger are now being built with overall lengths that are half as long as these ratings were seven years ago.

Manufacturers in today's market make every effort to ship complete units or assemblies of the largest size whenever possible. Fabricating a generator stator in sections that can be assembled in the field is an alternate procedure. Since accurate alignment of components is imperative, field assembly usually means elaborate and costly design considerations. Moreover, if complete shop tests are desired, additional assembly and dismantling of the stator are involved before shipment. Among other factors accounting for the manufacturer's preference for complete shop assembly are the expense and prolonged assembly time in the power plant, difficulty in obtaining experienced labor, and cleanliness controls equal to those found at the factory.

Consequently, field fabrication is employed only in the very largest stators when shipping limitations make it necessary. Experience has shown the procedure to be feasible. Field fabrication has proved satisfactory and no handicap to subsequent operations has been observed.

Clearance loads require special planning

The trend to larger turbine generators, stimulated by lower initial cost per kilowatt and the operating savings of the more efficient larger units, has resulted in ever-increasing traffic problems. Any shipment that exceeds railroad box-

car dimensions and weighs more than 140,000 pounds must move as a "clearance load" requiring special consideration. Blueprints of equipment requiring attention from a clearance standpoint are first reviewed by traffic men to determine limiting dimensions. In developing a prospective route, the railroads are surveyed. In addition, truck and water carriers are also considered.

The initial route is one over which the "through rate" applies with the type of car that is to be employed. If the railroads concerned can carry the shipment according to their published clearance factors, there is no problem. However, if the loaded measurements exceed the published clearance factors, applicable blueprints are sent to the affected carriers. Should any reply be negative, the route is revised by substituting other lines. The final route may be circuitous and in many cases may require the payment of combination rates and special charges. The increased freight cost is weighed against the possibility of sectionalizing the shipment with the incumbent added expense. If a rail route cannot be found, the design of the shipment may be altered to fit within the maximum dimensions. A combination of carriers may be used in the final routing.

Several types of special railroad cars are available, such as depressed center flatcars, long gondola cars, heavy-duty flatcars, and well cars. Since special cars are in short supply, every effort is made to use standard cars to conserve the much needed special equipment. Cars with carrying capacities from 50 to 250 net tons are available. If the gross weight on rails is the problem, the tare weight of the car as well as the number of car axles must be considered.

Truck and water carriers are doing their part in helping industry move heavy loads; however, state legislation limits the weight and size of loads that can travel on highways. Water carriers, on the other hand, are limited by deck load limits, dock facilities and cost of loading and unloading heavy loads.

Case history shows problem solution

A typical situation involving the shipping of large units developed when a generator stator 13 feet wide, 17 feet 6 inches high and weighing 436,500 pounds was shipped to the Atlantic Coast. Stators of similar size have been shipped without any clearance difficulties; however, the destination of this unit necessitated travel over bridge structures and several waterways. Special routing to keep within maximum dimension and weight limits resulted in transporting the stator over eight railroads and one car float. Figure 1 is a map of the route. The only car in the country suitable to carry the load was a 122-foot, 500,000-pound, 32-wheel depressed-center car owned by the Pennsylvania Railroad.

Arranging for this special car and insuring its availability on the loading date was the first step. The second step, obtaining a through clearance route, was not as easy.

Two months prior to the shipment, it was learned that a transfer float bridge had been rendered unsuitable for the load. This float bridge was needed to transfer the stator onto a barge for movement across a bay on the journey to its plant site.

It was estimated that nine months would be required to repair the float bridge to handle the consignment. In order to insure prompt delivery, a temporary draw bridge was constructed at a point adjacent to the disabled structure. Provisions were made to extend the railway tracks from their terminus to the new draw bridge.

After careful planning and many months of negotiation, the final route was established. This routing, however, required a three-inch off-center shifting of the generator stator to negotiate a bridge structure. Load shift was accomplished with the assistance of crane facilities supplied by adjoining railroads and supervised by company field superintendents. The consignment proceeded in this off-centered position for the next 60 miles and was then reshifted back on center.

Proper insurance was provided to protect the stator, railroad car, car float, and bridge. Special train service was arranged to insure a safe journey and prompt movement in transit.

STARTING 1970 MILE TRIP, the 450,000-pound stator leaves on special railroad car, one of the largest in the world. **(FIGURE 2)**

This particular shipment, and many similar to it, prove conclusively that by working together with complete carrier and manufacturer cooperation, traffic problems can be overcome and much can be accomplished.

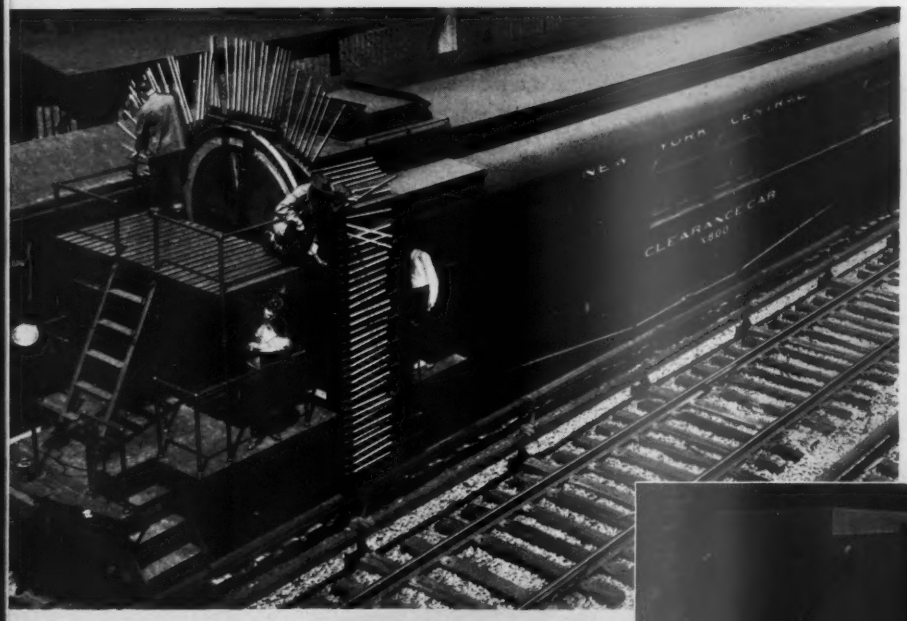
Cooperation will solve the problem

The demand for larger blocks of power needed to meet the rapid load growth of recent years will promote the use of large units. To keep pace with the shipments of larger component parts, improvements of transport facilities are indicated. Railroads have already begun removing obstructions, strengthening existing bridge structures and straightening curves; however, during the next few years the railroads probably will not be able to supply all the special equipment that industry requires to handle the special traffic tendered.

Industry is taking a positive approach to the problem by constructing and placing into operation special types of cars to meet specific needs. A manufacturer is thus assured of having a car of sufficient capacity available at a desired time and need not be concerned with prior commitments made on the limited number of cars presently available. Although the special car shortage is somewhat alleviated, at present it is still necessary to arrange for a special car as much as five months in advance.

Utilities are also helping to overcome the shortage by unloading equipment at plant sites without delay to make cars promptly available for their next assignment.

Proper recognition must be given today to the problem of shipping large components required by larger units. Manufacturers and carriers, by employing skilled personnel who work effectively together, can solve the problem of moving dimensional loads. Manufacturers can look forward to shipping equipment to any locale within a desired date. A vital service to the nation can only be accomplished by complete cooperation of all concerned.

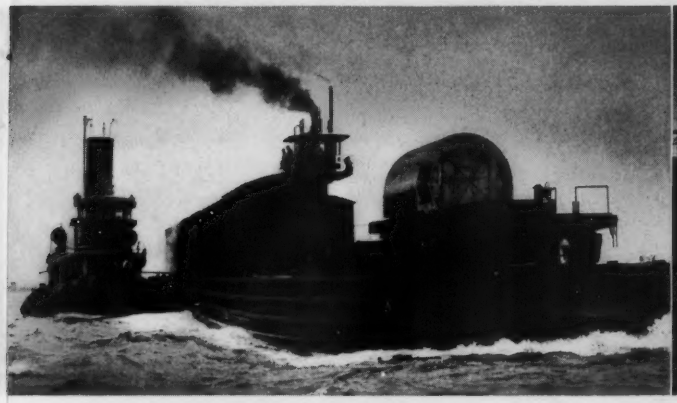


SHIPPING CLEARANCES are measured in places where they could be critical. The "feelers" on this car actually form an accurate shape of physical clearances. **(FIGURE 3)**
Photo courtesy of New York Central System

MEASUREMENTS PERMITTED special shipment to pass through this tunnel. No guesswork here — equipment proceeded on schedule. **(FIGURE 4)**

TRAIN RUNNING on special orders moved at restricted speeds. Diesel and 32-wheel carload is on last leg of trip. **(FIGURE 5)**

CRITICAL PHASE was movement of nearly 1,000,000 lb over specially built, temporary bridge onto car float. **(FIGURE 6)**



NEWSPAPERS RAN THIS PICTURE — huge stator and its car cross Hampton Roads from Norfolk to Newport News. **(FIG. 7)**

SUCCESSFUL journey's end — stator nears VEPCO's new Yorktown Station where it was raised to turbine room floor. **(FIGURE 8)**

STATOR INSTALLED with its turbine — the complete tandem-compound, double-flow turbine-generator develops 150 mw, which brings the total power plant capacity up to 340,000 kw. **(FIG. 9)**

RELAYING FOR GROUND-FAULT PROTECTION

by A. H. KNABLE
Switchgear Department
Allis-Chalmers Mfg. Co.

PROVISION for doughnut current transformer mounting is made in new type 5-kv switchgear for ground-fault relaying.

Ground relays can be selected to give maximum ground-fault protection to the load as well as the system. Simple curves provide the answers.

ALTHOUGH PHASE RELAYS will trip out with a line-to-ground fault, their relatively high settings prevent tripping out with the degree of sensitivity and speed needed to minimize damage. A ground relay with a 0.5 to 2-ampere range will allow a lower current and time trip-out when connected in residual with the phase relays, as shown in Figure 1. A doughnut CT surrounding the three-phase conductors, as shown in Figure 2, can better provide sensitive tripping.

Phase relays may be considered as one relay system and the ground relay connected to a doughnut CT as another relay system, each having independent settings. However, when the ground relay is connected in residual with the phase relays, the phase-relay time settings and the settings of the ground relays may be considered simultaneously.

Setting the ground relays on a system appears at first to be fairly clear cut. One might be tempted to begin by inserting too much impedance in the system neutral to reduce line-to-ground fault currents. To protect all but about 5 percent to neutral of the motor winding, approximately 20 times the minimum necessary phase-to-ground currents for ground-relay pickup will be required. Based on this assumption, the ground-relay tap and time-lever settings would be selected in the same manner as the phase relays.

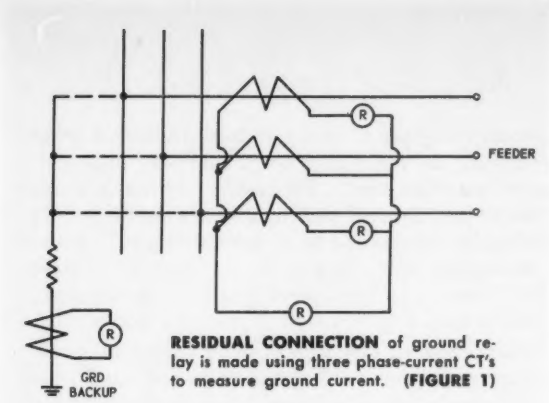
Avoid false trip

Perhaps the greatest reason for special consideration of ground-relay settings is the high excitation current of current transformers resulting from saturation. Because current transformers deviate from the ideal theoretical performance when they become saturated, or unidentically saturated when there are three-phase CT's involved, the desired low 0.5-ampere tap must be used judiciously with ground relays connected in residual. False zero-sequence currents cause a false tripping hazard with low ground-relay settings.

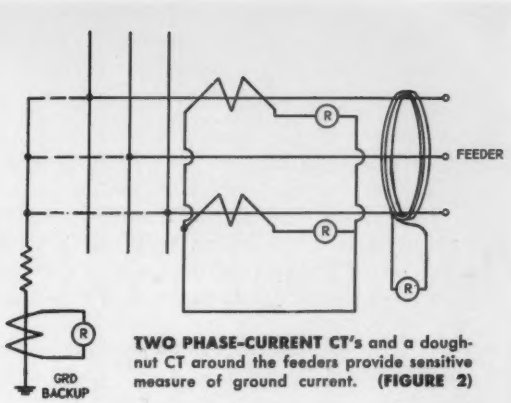
When the ground relay is connected to a doughnut CT, sensitivity resulting from excessive excitation is the factor to be considered. The excitation current can have a magnitude greater than the load current, thereby requiring a proportionately greater primary current. Because of the low number of ampere turns involved, reduced sensitivity from this cause is especially predominant with the lower ratio doughnut CT's.

For the ground relays connected in residual with the phase CT's, one obvious solution to the problem of false tripping is to increase the ground-current flow by reducing the system neutral impedance while setting the ground relay on a higher tap than 0.5 amperes. From experience it appears that with the false zero-sequence current, which is normally expected in the residual circuit, the ground relays should be set on the 1.5 to 2.0-ampere tap. The ground relay may be set on a lower tap or about 1.0 ampere, with the time lever increased to match that of the corresponding phase relays. Figure 3 gives the maximum burden that phase elements can impose on phase CT's before false currents sufficient to trip the ground relays are encountered. This false tripping occurs even with tap settings above 6 amperes in a residual circuit.

On the other hand, with the ground relay connected to a doughnut CT, the problem of choosing a combination CT rating-tap setting that will provide the best performance is encountered. The accuracy of a 200/5 CT — 0.5 tap combination for ideal CT's is identical to that of a 50/5 CT — 2.0 tap combination. For all practical purposes, this identity is also true because the Z burden varies



RESIDUAL CONNECTION of ground relay is made using three phase-current CT's to measure ground current. **(FIGURE 1)**



TWO PHASE-CURRENT CT's and a doughnut CT around the feeders provide sensitive measure of ground current. **(FIGURE 2)**

inversely as tap change squared. However, the CT ratio tap combination is still important. A 50/5 — 0.5 combination might prove to have an overall sensitivity greater than either of the other two combinations, and where extreme accuracy in coordination is not necessary, the 50/5 — 0.5 combination might prove to be best. By using a lower CT rating of 25/5, excitation current becomes so large that the minimum primary current required to trip is actually greater than for the 50/5 CT. This relation is shown in Figure 4. With high relay burdens, the 25/5 CT might prevent the relay from operating.

Extreme accuracy is not necessary where there are only two or three ground relays in series to be coordinated without unduly high time settings between relays. The time levers can be set far enough apart to assure coordination despite CT inaccuracies. In this case, low ratio CT's, such as 50/5 CT's with the 0.5-ampere tap, should prove more satisfactory than high ratio CT's, such as 200/5 CT's with the 0.5-ampere tap.

On a large system where there are many ground relays in series, the choice of 200/5 CT's with the 0.5-ampere tap relays should prove to be the proper choice because accuracy is essential to the closer time-lever settings of the many relays to be coordinated.

Use instantaneous elements with caution

Instantaneous relays are generally set on a high tap to avoid false tripping with transient inrush currents. The time relays, on the other hand, can be set on lower taps because they ride through transient periods. To avoid false tripping, the instantaneous-relay taps are conservatively set just below the pickup point for a full line-to-ground fault current.

For a residual connected ground relay with phase CT's and high ground current, this setting might be unnecessarily high. For the ground relay connected to a low ratio doughnut CT accompanied by a low ground current, this might not be high enough. In other words, for the doughnut CT the inrush to capacitors might be greater than the full ground current and an instantaneous element cannot be used.

The curves in Figure 5 are used for application purposes and relate the tap setting of relay, CT rating, percent of motor winding to be protected, and fault current mag-

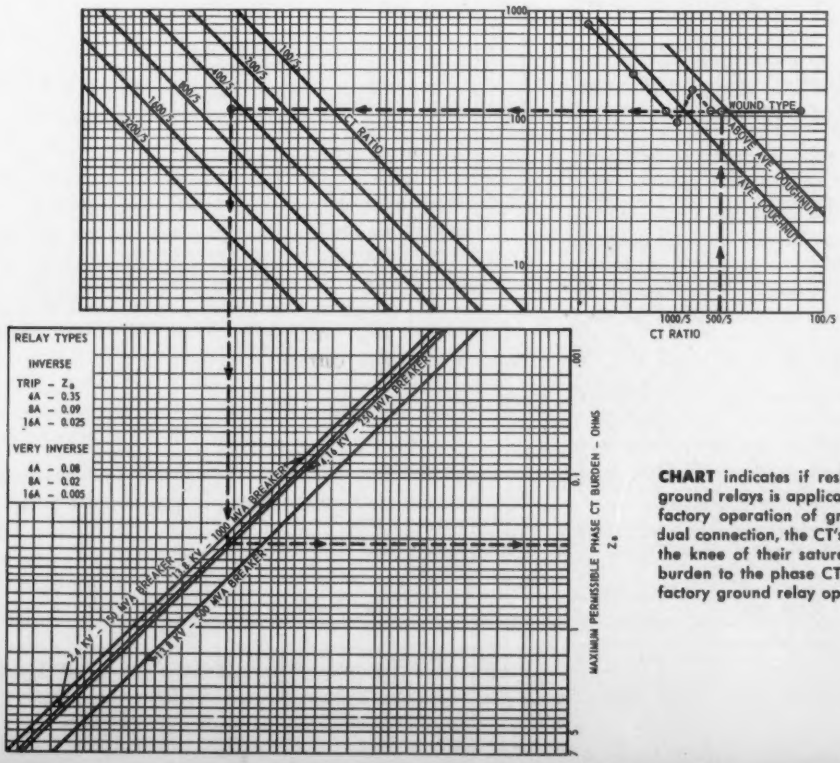
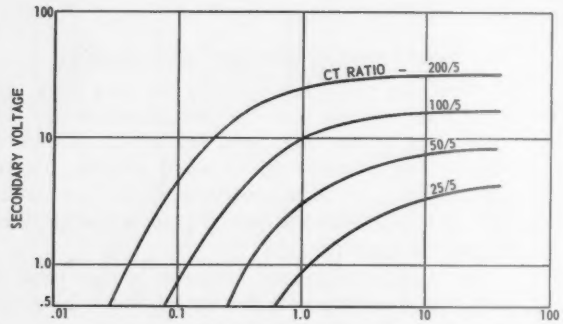


CHART indicates if residual connection for ground relays is applicable. To obtain satisfactory operation of ground relays in residual connection, the CT's must operate below the knee of their saturation curve. Adding burden to the phase CT's can cause unsatisfactory ground relay operation. **(FIGURE 3)**

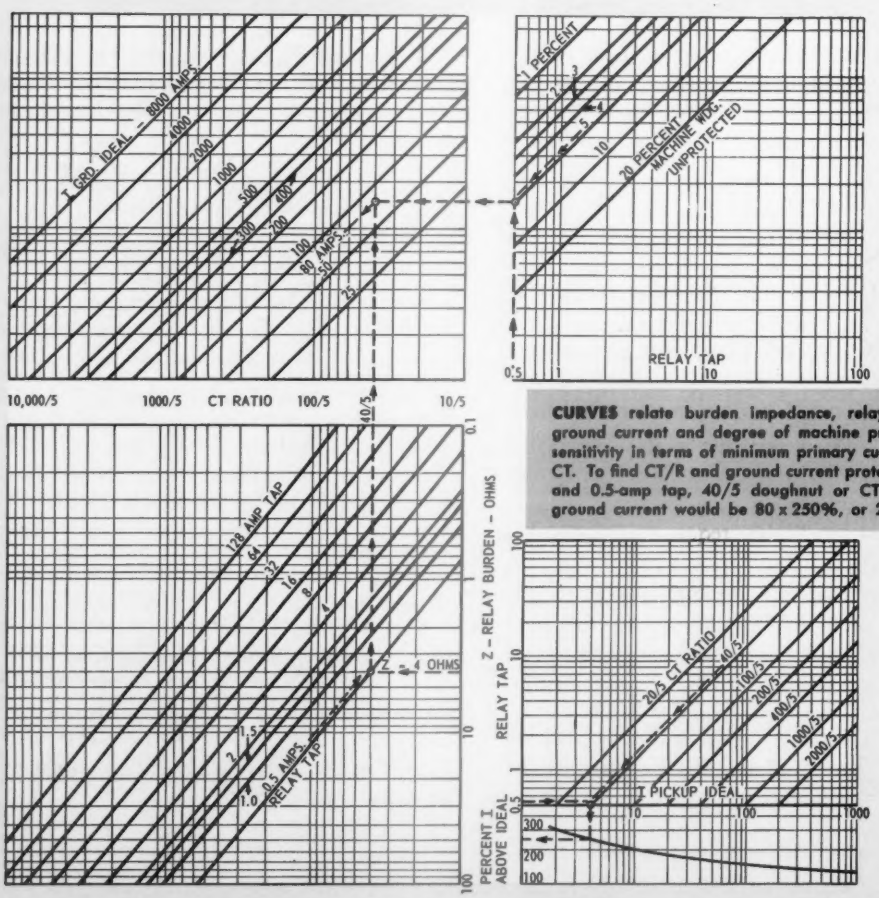
nitude. Leaving a winding with 5 percent to neutral unprotected is considered adequate, although the lower the better. However, there is no simple relation between the variable, because the excitation currents become relatively large, depending on the relay burden on the CT. With the percent increase in primary current due to the CT inaccuracy at hand, the ideal lines indicating fault current in Figure 5 can be multiplied by this percent increase, and the actual fault current required can be established. Figure 6 shows how the doughnut CT for ground relaying can be mounted on a new type 5-kv switchgear cubicle.

Another factor in ground relaying is the type of neutral impedance to ground. If a very large current to ground is required, the I^2R would be prohibitively high and a reactor would be used. For smaller currents a resistor would be used to avoid creating system overvoltages. The dividing line appears to be at approximately 25 percent of three-phase fault current. If the ground current required is less than 25 percent of three-phase fault current, a resistor is used; if greater than 25 percent a reactor is used.

When installing new switchgear or adding to installed equipment, the choice and setting of ground relays should be made with care. This precaution will assure sensitive, fast and well-coordinated relay action.



SATURATION CURVES of average doughnut CT illustrate that with low ratios the excitation current can greatly exceed the CT burden. **(FIGURE 4)**



CURVES relate burden impedance, relay tap and CT ratio with ground current and degree of machine protection to give maximum sensitivity in terms of minimum primary current in average doughnut CT. To find CT/R and ground current protection with a 4-ohm burden and 0.5-amp tap, 40/5 doughnut or CT would be used and the ground current would be 80 x 250%, or 200 amperes. **(FIGURE 5)**

ANSWER TO THIRD OVERLOAD RELAY QUESTION

by **R. A. GERG**
Control Department
Allis-Chalmers Mfg. Co.

THIRD OVERLOAD RELAY that can be installed in minutes is featured in starter line now being introduced. The additional relay, shown in a Size 1 motor starter, may save a motor. **(FIGURE 1)**

Controversial third overload relay can be quickly and easily added in new starter line.

WHILE TWO-PHASE overload protection is standard for three-phase motor starters, there has been considerable agitation to revise the codes to require a third overload relay on all low voltage motor starters. Numerous articles have discussed the pros and cons of this additional protection.

Some authors have been emphatic in their belief that the majority of motor controls should have three-relay overload protection, while others remain neutral but point out possible conditions that might require such protection. A third group feel that the additional relay involves a needless expense, since there are few occasions when three-relay overload protection is required.

As a result of this variance in opinion, the latest designs in motor starters have the standard two-phase protection with provision for an easy-to-install third overload relay. The relays can be installed in the field as easily as in the factory. Figure 1 shows how a third overload can be added to a standard starter.

Partially protected motor is vulnerable

The three-phase overload protection discussion involves a number of possible motor circuits in which two overload relays do not provide complete protection.

The most talked about situations in which two overload relays could prove inadequate involve motors fed from either delta-Y or Y-delta transformers having isolated neutrals. In this type of application the current in one phase of the motor could be as much as twice that in the other two phases if one primary line of the transformer is opened by fuse action or other cause. If the phase with the high current is not one of the two protected by standard overload protection, the motor phase winding will be damaged.

With the same transformer connection but with a delta or Y motor at standstill, the locked-rotor current in one phase through the motor control would be 100 percent normal three-phase locked-rotor current, while the other two-phase lines would carry only 50 percent normal three-phase locked-rotor current. With the high current in the unprotected line, the motor overloads would not operate fast enough to protect the motor.

TABLE I

Control Size	Motor HP at 440 Volts	List Price of Control	Motor List Price for 440 Volt 1800 Rpm	Cost of Motor and Control	Cost of Heater and 3rd O.L. Factory Installed	Percent Extra Cost for 3rd O.L.
0	5	$ 39	$ 212	$ 251	$ 6	2.4
1	10	44	372	416	6	1.5
2	25	84	628	712	10	1.4
3	50	138	1122	1260	25	1.9
4	100	308	2190	2498	40	1.6
5	200	684	4514	5198	70	1.4

Approximate prices given for comparison only.

Less commonly considered is another problem with the Y-delta and delta-Y transformers that results from unbalanced primary voltages. In this case a 2 percent overvoltage unbalance in one phase of the primary can result in a 15 percent overcurrent in one phase of the motor. Normal overload relays are selected for 125 percent full-load motor current trip. The additional 15 percent could mean 144 percent current in the one phase. Voltage unbalances of greater than 2 percent are quite common; with only two overload relays the high current may occur in the unprotected phase.

Single-phasing has side effects

Under certain load conditions, a small three-phase motor having two-relay overload protection and operating in parallel with a larger motor can also become a problem if one line of the power system supplying the motors is opened. The larger motor will supply power to the smaller motor, and one phase of the smaller motor will carry an overload while the other two lines will carry about normal or lower current. If the overloaded phase is unprotected with an overload relay, the motor will be damaged.

In a similar circuit, a single-phase load across two lines of a three-phase motor can cause a similar unbalance if the supply is single-phased. The unprotected line of the motor might be carrying an overcurrent with a two-relay-overload control, resulting in motor damage.

For complete motor protection three overload relays are generally specified when:

1. The motor is driving vital machines.
2. The motor is unattended.
3. Y-delta or delta-Y transformers supply the motor.
4. The transformer connections are not known.
5. Motors are operated in parallel with other motors or loads that might cause phase unbalance.
6. Local electrical codes require.

One utility reported that within a one-year period there were 300 known cases of motor burn-outs on their system resulting from single-phasing. The same utility reports that it suspects many additional unreported cases within the same period. Since the cost of the additional overload relay is usually less than 2 percent of the combined cost of a motor and starter, the addition may prove good insurance. Approximate increased costs are shown in Table I.

Because of the pressure imposed in various areas to change both local and national electrical codes by requiring the additional relay, the ease of adding the relay becomes important. New motor starter designs make it easy to add the third overload relay. If the motor circuit arrangement is not clearly free of possible single-phasing or unbalance problems, it may be economical to take advantage of this versatility.

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ELECTRONIC COMPUTING

a new key to engineering and scientific progress

by E. C. KOENIG
Engineer-in-Charge
Engineering Analysis Section
Allis-Chalmers Mfg. Co.

NEW PROGRAM is checked out on the IBM 704 computer to correct errors in the flow chart, coding and key punching. **(FIGURE 1)**

Increasingly larger and more complex problems are being solved on computers. This basic discussion will help in the understanding of computer operation and potential.

DURING THE 1940's various types of analog computers were applied to engineering problems. Some of these units were special purpose machines designed and built by product design engineers. Computers have accurately predicted product performance for a number of years and current machines can solve some of the largest and most complex design and manufacturing problems.

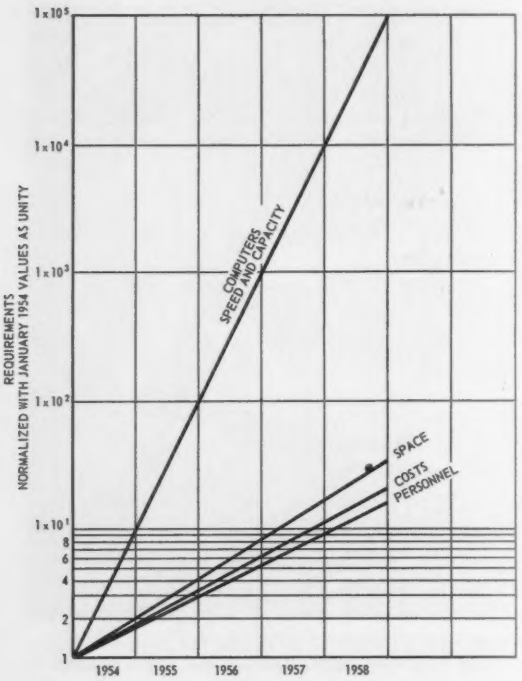
Facilities have been and are being expanded with larger digital and analog computers. Equipment is used at maximum capacity and machines with greater problem solving capacities are replacing older machines every 1½ to 2½ years. As equipment tends to become obsolete and before new equipment can be installed, time is purchased on the most current machines at universities and other research centers. Digital computers are rented and replaced with larger machines. Electronic analog computers are purchased and old equipment is either retired or retained for solving small problems.

The growing size and complexity of business and manufacturing activity have made it mandatory that computers be used to solve problems. The plots in Figure 2 show that since 1954 the requirements for computers with speeds and capacities to solve larger and more complex problems have increased tenfold each year or doubled approximately every three months. Personnel directly responsible for problem solutions have doubled every 15 months; space requirements for personnel and equipment have doubled every 12 months; and costs, including personnel and equipment, have doubled every 13½ months.

The objectives in the application of large capacity computers can best be explained by a simplified block diagram of an industry, shown in Figure 3. In-line processing functions are those operations which process raw and pre-processed materials, shown as input, to form useful products, shown as output. Control functions pertain to the control of the processing functions and are connected through communication channels as shown. Examples of control functions are production scheduling, inventory control, standard engineering design, and the like. Creative functions are those which require original thought, such as research, invention, engineering and mathematical analysis, and business planning.

Computers are applied principally to the control functions involving repetitive mental tasks, thus freeing affected personnel for creative activity. In some industries it is possible for all the repetitive control functions to be taken over by computers, but in the more complex processing industries something less than this is the practical limit.

The increased demand for electronic computers brought about by expanding applications, more complete and accurate analysis of systems, and an expanding economy is resulting in an electronic computing age that compares with the mechanical machine age. Computers will contribute as much as mechanical machines to our material well-being. As modern roadbuilding machinery has eliminated the physical labors accompanying the use of hand tools, electronic computing machines eliminate the repeti-



PLOT SHOWS the growth of requirements of space, personnel, costs, speed and capacity of computer operation. **(FIGURE 2)**

tive mental labors associated with the pencil and slide rule. The scope of accomplishment is tremendously enlarged by the electronic computer.

Numbers are basis of digital computer

The digital computer operates on discrete quantities or numbers. If the computer were to use the decimal number system, based on powers of 10, it would be required to recognize a different voltage symbol for each of the 10 number symbols from 0 through 9. Instead, to reduce the complexity of a digital computer, it operates on the binary system, based on powers of 2. For this system only two different voltage signals need be used to represent the two number symbols which can be called zero and one. To obtain a binary system representation of the decimal system, the symbol 1 is added successively to the previous sum and there is obtained the following:

Decimal	Binary
0	0
$1 = 2^0$	1
$2 = 2^1$	10
$3 = 2^1 + 2^0$	11
$4 = 2^2 + 0^1 + 0^0$	100
$5 = 2^2 + 0^1 + 2^0$	101
$6 = 2^2 + 2^1 + 0^0$	110
$7 = 2^2 + 2^1 + 2^0$	111
$8 = 2^3 + 0^2 + 0^1 + 0^0$	1000
$9 = 2^3 + 0^2 + 0^1 + 2^0$	1001

The simplicity of adding any two of the above binary numbers is demonstrated in the following example:

Decimal	Binary
$+4$	$+\ 100$
$+5$	$+\ 101$
$+9$	$+\ 1001 = 2^3 + 0^2 + 0^1 + 2^0 = 9$

The principle of counting digits of a binary system is applied in a digital computer to accomplish the three mathematical operations of algebraic addition, multiplication, and division. Most digital computers of today have a precision of 35 binary digits, equivalent to 10 decimal digits. The 35 binary digits plus an additional digit to designate sign constitute a word of information of 36 binary digits.

Storage of information is a vital function of any digital computer. Storage speed is defined by the rate that a word of information can be placed into storage in a desired location and the rate a word can be found and taken from storage. Magnetic core memory is the most common high-speed storage presently used in the larger computers, but slower magnetic drum storage is used in the smaller machines. Magnetic tape storage, common to all computing machines, serves well for bulk storage of information which is used occasionally. Blocks of words of information from tape are usually placed in high-speed storage to process the individual words of information.

Words of information containing 36 binary digits may be instruction words or data words. Information in data words may be interpreted as numerical or alphabetical. The basic mathematical operations of addition, multiplication and division are performed on numerical data words. Stored alphabetical data may be used to identify numerical data. The typed output of the computer appearing as a number may be identified, for example, as a length by having the word "length" typed beside the number value.

Instruction words guide the computer through a predetermined sequence of operations. For example, to obtain the product of two numbers, the computer must know where to find the multiplicand and the multiplier, must be told to perform the multiplication and must know what to do with the product. Such instructions are called a program. When a computer gets its instructions from its memory storage it is called a stored program computer.

Although a digital computer operates on a binary system, programs need not be prepared in the binary system. Instead, an alpha-numeric coding system is used in preparing the instructions. The resulting coded instructions are then translated by the computer itself to the binary system by a separate set of instructions called an assembly program. Information output of the computer may also be translated and typed out in the alphabetic form and in the decimal number system.

Analog operates on continuous voltages

The analog computer operates on continuous voltages and problem solutions are obtained as measured voltages. An electrical circuit is constructed on a patchboard using

patchcords. These patchcords connect the various components of the computer in a predetermined manner to simulate the physical system under study. The voltages of the resulting computer circuit are generally not constant but vary with time and are recorded in graphical form as a function of time on a recorder or oscilloscope. The amplitudes of the voltages are measured from the graphs at desired values of time. The problem solutions which are these voltages and times are no more accurate than they can be measured. Three-digit accuracy is considered maximum.

The electronic analog computer differs from a direct analog-type computer such as the network calculator or network analyzer used for analyzing power systems. In power system analysis, inductance, resistance, and capacitance of transmission lines perhaps many miles in length are directly represented in the network analyzer by variable lumped inductance, resistance, and capacitance perhaps several inches in length. These components are connected by wire leads to simulate the complete power system.

To simulate a system by an electronic analog computer, a mathematical description of the system must first precede the simulation by the computer. The derived mathematical functions are in the form of differential equations. The principal components required by the electronic analog computer in solving linear differential equations are:

Adders

Multipliers (to obtain the product of a constant and a function)

Integrators

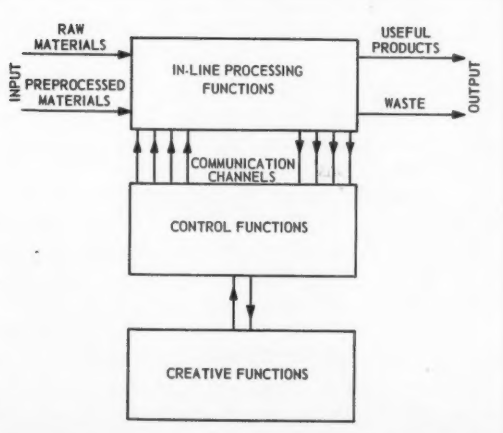
When the differential equations are nonlinear the following components are also required:

Function generators

Diode limiters

Servo resolvers

Multipliers (to obtain the product of two functions)



INDUSTRY block diagram shows principal computer functions. Control functions are main area of application. **(FIGURE 3)**

Electronic amplifiers are used in the construction of most of these computer components. To prepare a problem, a circuit diagram showing how the computer components are to be connected is prepared from the equations describing the physical system. Relationships are established between the quantities of the computer circuit and the corresponding quantities of the physical system.

Problem determines computer selection

The computer to use for a particular type of problem is usually determined by considering the basic operation of digital and analog machines. Since the digital computer directly performs algebraic addition, multiplication, and division, physical systems described directly by algebraic equations are well suited for the digital computer. Even small systems of algebraic equations are usually impossible to solve on the electronic analog computer. Routine design calculations of products and problems of shop scheduling in manufacturing are examples of problems well suited for the digital computer.

Since the electronic analog computer solves differential equations directly with its integration components, it is well suited for analyzing dynamic physical systems, that is, systems which are described by differential equations, assuming accuracy of the computer is no limitation. These types of problems may also be solved on the digital computer by some numerical method of solving differential equations, but they are most economically solved on the electronic analog computer particularly when:

A problem is non-repetitive.

Parameters of the system must be varied arbitrarily to obtain a desired performance (parameters can be readily varied on an analog computer by simply turning knobs).

Equipment changes in the physical system must be made to obtain a desired performance, such as compensation changes in feedback systems (such changes are simulated readily on the analog computer by changes and additions in the computer wiring circuit).

Electrical control and speed governor systems are examples of systems best analyzed on the electronic analog computer.

Some systems described by differential equations are impossible to analyze on the electronic analog computer because of insufficient accuracy in the solutions and must be solved by digital computers. This is true for those systems in which the matrix of equations that describe the system has many non-zero elements, and for those systems described by partial differential equations where these equations are then approximated by very large systems of ordinary differential equations. Examples are problems of transient heat flow, and flux distributions in nuclear reactors.

Occasionally it is desirable first to analyze a system on the electronic analog computer to optimize on a solution, making use of features of this computer to simulate changes readily, and finally arrive at an accurate solution on the digital machine.

Problem preparations are many and varied

In general, the steps required to predict the performance of a physical system on a computer are the following:

1. Analysis of the system
2. Numerical analysis
3. Establishing the computer flow chart
4. Machine coding
5. Testing

The analysis of the system requires a thorough fundamental knowledge of the system in order to establish an accurate and complete mathematical description. The approach in describing the system may be very different from that used for manual calculations or for computers with less speed and capacity than the one to be used. In most cases the analysis should yield results which are a great improvement over those obtained manually. The analysis for a digital computer solution should be as general as possible so that the analysis applies without exception to special conditions which may arise.

The numerical analysis is required for digital computer solutions and may parallel the analysis of the system. Since the digital computer can perform only addition, multiplication, and division, all mathematics must be reduced to these simple mathematical operations. Trigonometric and hyperbolic functions must be calculated in series form. Mathematical expressions appearing as differential equations must be solved by numerical methods, and truncating and roundoff errors and convergence must be explored when the different numerical methods are applied. Large sets of simultaneous equations may best be solved by iteration methods rather than by direct solution. These are just a few examples of what might be required in a numerical analysis.

Establishing a computer flow chart is required for both types of computers. The digital flow chart may be considered a map for the computer to follow in performing the required calculations. There are intersecting roads or paths when it must be decided which of two roads to take or which of two calculations to perform next. The choice is based on a comparison of the magnitude of two numbers where either one or both numbers may be the result of a previous calculation. This feature of the computer to take alternate courses of action is very important in the solution of complex problems.

The flow chart of the electronic analog computer is a wiring diagram which describes how the different components are to be connected to solve the differential equations describing the system. Consideration must be given to the limitation of the characteristics of the components to avoid difficulties in the computer operation.

Coding is a word more frequently associated with a digital machine, but a form of coding is also required for the electronic analog computer. Coding follows the establishment of the flow charts. For the digital machine, coding is the writing of the computer instructions from the flow chart for a specific make and model machine and usually requires a small percentage of the total time required for problem preparation. Coding is often done simultaneously with the drawing of the flow chart.

Coding for the electronic analog computer can be considered to be the establishing of the relationships between the computer quantities and the quantities of the physical system, and the recording of the resulting values of the computer constants on the flow chart. Consideration must be given to frequency and voltage limitations and the noise of the electronic components when establishing these constants for the computer circuit.

Testing of a digital program is required to correct errors in the flow charting, coding and key punching. It may be that errors in the analysis are found at this time. Testing

LATEST MODEL electronic analog computer includes two consoles for solving two problems simultaneously. A combined operation of the consoles solves a single, large complex problem. **(FIGURE 4)**

of a program or problem circuit on the analog computer is also required to correct errors in the flow chart, constants of the circuit and the wiring of the patchboard.

There is no fixed method for testing. Each problem is unique and requires the ingenuity of the individual doing the testing. The reason for this can be appreciated when it is realized that it may take many man-years of effort for a comparable manual solution. A duplicate manual calculation is therefore impossible. The general approach is to check out the system in parts and to consider an idealized physical system. After a program for a digital machine or a patchboard circuit for an analog computer is thoroughly checked out, it may be stored and used to solve all problems of the type for which it was established.

Look to the future

Computing is still in its infancy. The requirements for computers with greater speeds and capacities is increasing tenfold every year and this phenomenal growth can very well continue far into the future. It will be possible to control data flow and certain data-processing functions from locations remote from the central computing facilities. Computers of the future are likely to become more and more like nerve centers as they take over more of the repetitive manual control functions. Technologies and advanced methods for analyzing physical systems may result in completely new computer designs and changes in the present procedures for preparing problems for computer solutions.

The IBM 704 Digital Computer is briefly described as follows:

Word Length
- 36 binary digits (10 decimal digits plus sign)

Speed of Operations
- Algebraic addition, 12,000 per second (floating point)
- Division, 4500 per second (floating point)
- Multiplication, 4000 per second (floating point)
- Logical, 42,000 per second

Storage
- High-speed magnetic core, 8192 words, 12 microseconds access time

Input
- 250 cards per minute

Output
- Line printed — 75 lines per minute
- Cathode-ray display, 21-inch tube (used for displaying plotted information)
- Cathode-ray recorder, 35-mm camera (for photographing plotted information)
- Punched cards — 100 per minute

The 231R Electronic Analog Computer is the latest model computer manufactured by Electronic Associates. The components are:

Two consoles for solving two problems simultaneously. Consoles may be combined for analyzing single complex problems. Passive components of $\pm$ 0.01 percent accuracy installed in temperature-controlled oven.
- 66 adders
- 44 integrators
- 10 inverters (sign changers)
- 120 potentiometers (coefficient multipliers, coefficients less than unity)
- 6 function generators
- 6 function multipliers
- 2 servo resolvers
- 2 diode limiter units

Additional equipment can be added to both types of computers to increase their problem-solving capacities.

The applications of electronic computers have increased rapidly since their use began. The present problem areas where computers are being applied and some examples are shown below.

1. Power System Studies
   - Load flow
   - Short circuit
   - Stability
2. Electrical Control and Governor Systems
   - Diesel engine-generator speed governors
   - Steel mill control systems
   - Voltage regulating systems
   - Steam and hydraulic governor systems
3. Electrical Machine Design
   - Optimum design of power and distribution transformers
   - Salient-pole synchronous motors and generators
   - Induction motors
4. Mechanical Machine Design
   - Design of cement kilns
   - Transient and steady-state heat flow and temperature stresses
   - Torsional and lateral vibrations
   - Heat balance in steam turbines
   - Thermal pipe stresses
5. Nuclear Reactor Design
   - Reactor simulation
   - Flux distributions
   - Transient thermal stresses
6. Manufacturing
   - Shop scheduling
   - Transportation

NATION'S LARGEST PUMP-TURBINE scroll case and stay ring, with 11 sister units, will serve the New York State Power Authority's Tuscarora Plant. Unit inlet is 18 feet in diameter and measures 56 feet across. The completed installation will include 12 reversible pump-turbines and 12 generator-motors. The combined power output as pump-turbines will be greater than any other pump-turbine plant in the world. Each unit, as a 37,500-hp motor-driven pump, will deliver 3400 cubic feet per second against a storage reservoir head of 85 feet. In reverse rotation as a turbine rated at 28,000 hp at 75 feet of head, each unit becomes a 25,000 kva, 0.8 pf generator.

Allis-Chalmers Staff Photo by Michael Durante

KEEP IT CONFIDENTIAL

by **HENRY J. MARCINIAK**
Patent Attorney
Allis-Chalmers Mfg. Co.

LAW OF TRADE SECRETS provides a means of protecting your proprietary information. A simple stamp serves as a warning against improper and illegal use of information.

Failure to safeguard your company's technical know-how may result in loss of valuable rights

IN MODERN BUSINESS it is not generally possible to lower an iron curtain of absolute secrecy on various phases of a business operation. Disclosure of technical know-how to the people closely involved in carrying out a business operation cannot be easily avoided. However, despite these disclosures, the law of trade secrets as applied by the courts today affords the businessman a large measure of protection for technical know-how. Judging from the number of court decisions in which companies have lost valuable rights, some responsible businessmen appear to be unaware of the benefits of safeguarding know-how under the law of trade secrets.

The term "technical know-how," as used today, covers the accumulated skill, experience, special techniques, and technological information which enable a company to design and manufacture a product successfully. It does not include the patents of a company.

Although technical know-how is not carried on the company's balance sheet, it is a most important asset. The acquisition of this asset represents a sizable investment. Unlike a company's physical plant or inventory, the company's technical know-how can be inadvertently donated to competitors if it is not adequately safeguarded.

All know-how is not protectible

All of a company's store of accumulated technical know-how is not protectible under the law. Obviously, a company that possesses an outstanding research or engineering team has no right under the law of trade secrets to prevent competitors from hiring members of the team. Likewise, ideas which are not embodied in the concrete form of drawings, specifications, or compilations of data are not protectible. While a company's technical know-how includes the ability to apply published manufacturing and design data, the company has no right to exclude others from using such published data.

A drawing is the most common form in which a company's technical know-how is incorporated. A drawing will frequently disclose detailed manufacturing dimensions, heat treatments, tolerances, finish requirements, circuit components, fabrication schedules, shop processes, material specifications, supply sources, and other manufacturing and engineering data. Such a drawing is shown in Figure 1. This type of information can be protected.

Underlying the law of trade secrets is the recognition of the right of one who has spent time, money and effort to prevent others from pilfering the resulting work product. In other words, the law recognizes a proprietary interest in the work product. For this reason, know-how which is protectible is commonly referred to as proprietary information. Figure 2 shows one type of information that is protectible.

How to keep it confidential

A basic requirement of the law is that overt action to establish the confidential character of the information must be taken either by nondisclosure or by disclosure to others in confidence. Neglect of responsibility in this respect may result in the loss of valuable rights.

To maintain the character of the information confidential does not require that it be kept absolutely secret. In any large manufacturing operation drawings containing proprietary information must necessarily be distributed to various employes and, in some instances, to outsiders. If the disclosure is limited to those personnel who need to know the information, and who are instructed not to divulge the information to others, the rights of the company are not jeopardized.

The preparation of contract proposals very often involves a considerable expenditure of time, money and effort. Such contract proposals can be protected if the confidential character of the information is clearly established by stamping on the proposal a proprietary marking of the type shown in Figure 3. If a customer discloses your proposal to a competitor, the customer may be subject to legal liability, since he has been made aware of your proprietary interest in the proposal. If you can prove that your competitor improperly used the proprietary information, you may have legal recourse against him.

As a matter of general practice in industry, the notation "Confidential" is employed on disclosures containing proprietary information. On a drawing the notation may appear in the legend or some other prominent location. In effect, the notation warns anyone receiving the information that they are not to divulge it to others. Failure to provide such marking or its equivalent may result in the loss of rights to the proprietary information.

Proprietary rights are commercially valuable

An owner of proprietary information has two important rights:

(1) The right to expect others to keep confidential the information which is disclosed to them in confidence.

(2) The right to prevent use by others of information improperly obtained from the owner.

Like a "No Trespassing" sign, the real value of the protection afforded under the law of trade secrets probably resides in its deterrent effect. The possibility of incurring legal liability for disclosing or improperly obtaining and using another's proprietary information should convince the less ethical businessman that he cannot afford to stray from the straight and narrow path. If it is necessary to acquire the right to use another's proprietary information, sound business practice requires that it be obtained from the owner with his consent.

Unlike rights under a patent, the rights under the law of trade secrets are not exclusive; that is, in the absence of proof that a competitor has improperly obtained your proprietary information, the competitor incurs no liability. The significant commercial advantage of patent protection is the right to exclude others from making, using or selling the invention for a period of seventeen years. If a competitor infringes the patent, he is liable for infringement even though he is unaware of the patent. Under the law of trade secrets, however, one party is not prevented from independently developing the same proprietary information that may be owned by another party. It is possible, therefore, that more than one party may have rights in identical proprietary information. Under the law of patents more than one valid patent cannot be granted for the same invention.

Proprietary rights augment patent rights

If proprietary information meets the requirements for patentability and cannot readily be kept a secret, as a general rule, a patent application should be filed. Usually, the exclusive right of the patent grant is more useful commercially than any right under the law of trade secrets.

A decision to protect a patentable development under the law of trade secrets may lead to difficulties. There are many "loose strings" attached to the protection under the law of trade secrets. If every reasonable effort to prevent disclosure is not exerted, rights may be lost. *Once lost, these rights to proprietary information cannot be regained.* When a patentable development is kept as a trade secret for more than a year before filing a patent application, the right to patent protection may be lost.

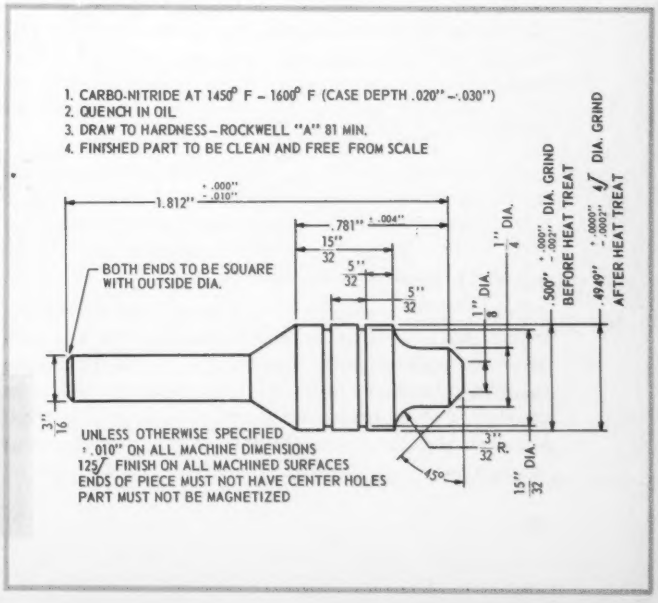
With commercially significant patentable developments, it pays to play safe and obtain patent protection. However, there are exceptional cases in which definite commercial advantage can be obtained by secrecy, regardless of patentability.

Under our free enterprise system a competitor has the privilege of copying your product, provided he does not infringe one of your patents or copyrights, and does not confuse the public as to the source of his product. If your technical know-how embodied in the product cannot be ascertained from the product or by an analysis of the product, including reverse engineering, a competitor is not free to copy or reproduce your product. Therefore, you can enjoy a monopoly so long as this know-how can be kept secret.

Secrecy protected Stradivari's violins

In the old days safeguarding valuable know-how was relatively simple. Most products were made by individual artisans whose know-how was passed down from father to son or from artisan to his apprentice. Business was not as intensely competitive as it is today.

Consider a product like Stradivari's violins. For centuries craftsmen have been able to copy Stradivari's method of constructing violins, but they have been unsuccessful


1. CARBO-NITRIDE AT 1450° F – 1600° F (CASE DEPTH .020"–.030")
2. QUENCH IN OIL
3. DRAW TO HARDNESS – ROCKWELL "A" 81 MIN.
4. FINISHED PART TO BE CLEAN AND FREE FROM SCALE
1.812"
.781"
BOTH ENDS TO BE SQUARE WITH OUTSIDE DIA.
DIA. GRIND BEFORE HEAT TREAT
DIA. GRIND AFTER HEAT TREAT
UNLESS OTHERWISE SPECIFIED
±.010" ON ALL MACHINE DIMENSIONS
125 FINISH ON ALL MACHINED SURFACES
ENDS OF PIECE MUST NOT HAVE CENTER HOLES
PART MUST NOT BE MAGNETIZED
45°

MANUFACTURING KNOW-HOW is often revealed on drawings and specifications that may be given to a supplier or a customer. Such information can be protected by simple safeguards. **(FIGURE 1)**

in reproducing the finish which is responsible for the superb tonal quality of a Stradivarius. The method of making a violin can be readily ascertained by a craftsman from an examination of the violin. Ingredients of the varnish used by Stradivari were generally known to the trade in his day and could be readily analyzed today. However, to prevent competitors from duplicating his violins, Stradivari kept two things secret:

(1) The manner in which ingredients in the varnish were proportioned.

(2) The method of applying the varnish.

If Stradivari were to produce his violins for the first time in today's business world, it would be possible for him to protect his varnishing techniques under the law of trade secrets. His method of applying varnish would necessarily have to be disclosed to a number of his employes. If the method by itself were patentable, his patent attorney would likely advise him to have it patented, but the attorney would recommend that the manner in which the ingredients in the varnish are proportioned not be disclosed in the patent application. This information can be effectively protected under the law of trade secrets. Until his competitors independently discovered the secret Stradivari would maintain his monopoly and prevent competitors from duplicating his violin.

Smith Brothers' cough drops, Angostura bitters and Coca-Cola syrup are modern examples of exceptional cases under the law of trade secrets. Many have attempted, without success, to duplicate these jealously guarded trade secrets. The protection afforded under the law of trade secrets has been the most important factor enabling these companies to successfully maintain their competitive position.

Ingredient is kept secret

Chemists have succeeded in determining the exact caffeine, phosphoric acid, phosphoric pentoxide and caramel content of Coca-Cola syrup, but they have not been able to determine the precise identity of the flavoring ingredient. To protect its product under the law of trade secrets, the company discloses the identity and composition of the flavoring ingredient, known as 7X, to only a few of the most trustworthy employes and officers of the company. By keeping secret a selected ingredient, the company has been successful in preventing competitors from duplicating the syrup and from making any effective inroads into its domination of the market.

A competitor cannot be prevented from duplicating run-of-the-mill products manufactured by industry today, except under the patent system. Modern technology has made it too easy for competitors to analyze and reverse engineer product improvements.

Even though a competitor can obtain unpatented improvements by reverse engineering, he does not acquire a right to your proprietary information. He must develop his own proprietary information that will enable him to successfully incorporate your improvements into his product. You will have a competitive advantage during this time.

Each unpatented improvement of a product, protectible under the law of trade secrets, is an addition to the asset side of your know-how balance sheet. This valuable commodity can be sold or it can be licensed for a royalty. If you have disclosed your know-how by publication, you have lost your proprietary rights and have made an addition to the liability side of your know-how balance sheet.

Proprietary information can be donated

There are many recorded cases of companies that have inadvertently given away valuable proprietary information by disclosing it in a publication. The following is a typical case:

X Company developed a glass-bonded mica insulating material at a great expense. The improved material was highly successful commercially. The technical know-how that made it so successful was the data that the X Company had developed on the suitability of the different types of frit for particular applications. This data was the result of extensive experimentation to determine critical temperatures, proper heating, cooling periods, pressures, and other factors.

Representatives of Y Company, a supplier of the frit, made frequent visits to X Company's plant and observed X Company's manufacturing operation. Advertising brochures of X Company contained a detailed description of the compositions used in different applications and also of the method of manufacturing the insulating material. Articles describing the insulating material were written by employes of X Company and published in various technical journals.

Y Company then entered into the business of manufacturing and selling the identical insulating material made by X Company. Although X Company sued Y Company to prevent use of its technical know-how, it was unsuccessful because it had lost its proprietary rights by the disclosures in the advertising brochures and in the articles written by X Company employes.

Clearly, X Company could have prevented Y Company from using its data if it had not destroyed its proprietary rights in the data by publication, or if it could have proved that Y Company improperly acquired the data. The economic consequences of losing proprietary rights can be very serious. X Company made it possible for competitors to enter the field and had to write off the development costs. Y Company entered into a new business with the competitive advantage of not having to defray the full development costs.

To illustrate a point, let us assume that X Company had filed a patent application covering the composition of the insulating material. Since a pending patent application is treated as confidential by the government, X Company would not be deprived of its rights under the law of trade secrets. However, the eventual publication of the patent, like any other unrestricted disclosure, would destroy X Company's rights under the law of trade secrets.

Technical articles are often source of losses

Quite often an employe of a company will publish an article containing proprietary information while relying on a patent application. The company would still lose

its proprietary rights by the publication, to the extent of the information disclosed. However, when the patent issues, the patent law gives this company the right to exclude others from making, using or selling the product or process covered by the patent.

If you disclose proprietary information while relying on the probability of a patent issuing *and the patent does not issue*, you lose all your possible rights. If a patent issues and the proprietary information disclosed is not covered by any claims of the patent, you lose your proprietary rights.

A situation similar to the one which X Company faced occurs frequently because personnel rely on the probability that a patent will issue having claims covering the proprietary information disclosed in the patent application. A good rule is never to disclose through publication any proprietary information that might give a potential competitor some commercial advantage.

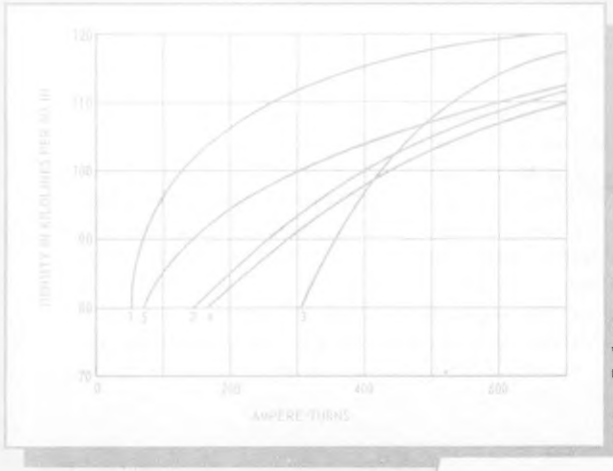
Contract proposals must be protected

A common way to lose proprietary rights in technical know-how is through failure to require customers to treat as confidential contract proposals which involve detailed engineering specifications. A customer may disclose your detailed engineering specifications to other manufacturers for the purpose of obtaining a lower bid. Unless a contract proposal is kept confidential by restrictive markings, valuable proprietary information may be forfeited and the sale lost.

Even though the customer may eventually obtain an unrestricted disclosure of your know-how when he accepts the proposal or when the product is delivered to him, you are not deprived of proprietary rights during the period of negotiation. Under the law of trade secrets you are afforded protection until the unrestricted disclosure takes place. By failing to treat a contract proposal as confidential, you prematurely cut off your proprietary rights at a time when they may be of most value to you. An ethical customer will not disclose or improperly use your proprietary information.

To safeguard your proprietary rights, therefore, it is essential that any proprietary information be transmitted on the condition that the party shall treat it as confidential and shall not disclose it to others. Failure to follow such procedure will result in the loss of valuable rights under the law of trade secrets. In a legal sense, any unrestricted disclosure amounts to a release of rights.

The law of trade secrets is fundamentally nothing more than a rule of fair play. In good conscience, one should not be permitted to pirate the work product that is the result of another's time, money and effort. The courts recognize that the law of the jungle does not govern business relationships. The rights available under the law of trade secrets are commercially valuable but are also very fragile. The proper safeguarding of these rights requires expert planning and help.



PROPRIETARY INTEREST in a work product, such as test data, resulting from the expenditure of time, money and effort is recognized by the law. **(FIGURE 2)**

KEEP IT CONFIDENTIAL by proper notations. Drawings marked "Confidential" and "Property of," with the owner's name affixed provide the owner with a safeguard recognized by the law. **(FIGURE 3)**

applying DIFFERENTIAL EQUATIONS to induction motor transients

by H. S. NEUVILLE
Application Engineer
Electrical Application Dept.
Allis-Chalmers Mfg. Co.

What happens to speed when disturbances in cage motor voltage or load occur? This question is important to those applying large motors to critical loads. Solution to these equations can provide answers.

THE USE OF THREE-PHASE INDUCTION MOTORS in process control and test facility drive systems has increased the interest in predicting their dynamic behavior. Satisfactory indications of actual machine performance are possible when motor differential equations are solved on either an analog or digital computer. The equations summarized can be used to:

1. Generate the motor's dynamic and steady-state speed-torque capability curves.

2. Predict acceleration time for a given inertia and load.

3. Show the motor's response to impact loading.

4. Illustrate the motor's reaction to line voltage fluctuations.

DIFFERENTIAL EQUATIONS for induction motors are solved by analog computer using circuitry set up on computer patchboard.

5. Trace the family of speed-torque curves for wound-rotor motor action.

The differential equations are written for a motor with certain ideal characteristics. They are:

1. Voltages and currents vary sinusoidally with time in symmetrically arranged primary and secondary windings.

2. Mutual inductance is a cosinusoidal function of the magnetic angle between the primary and secondary windings.

3. Flux is linearly related to current.

4. Eddy-current and hysteresis losses are negligible.

5. A balanced three-phase condition exists at all times. (Negative-sequence currents are zero.)

In short, the differential equations describing transient performance are predicted on the same criteria as used to predict steady-state action from an idealized equivalent circuit.

Three-phase equations are defined

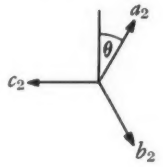
The instantaneous voltage of each phase winding measured line to neutral in an induction motor is

$$v = ri + p\,(\psi) \text{ or } ri + \frac{d(\psi)}{dt} \qquad (1)$$

Six equations of type (1) completely describe cage motor voltage and current transients. Three equations apply to the motor primary (stator) and three apply to the motor secondary (rotor).

The co-ordinate axis in space of the three primary equations is that of conventional three-phase orientation with the arrows indicating positive directions of current, flux linkages and applied voltage.

The co-ordinate axis of the three secondary equations is similarly orientated except that the vectors lag the primary set by the magnetic angle θ.



Since the air gap is uniform, the magnetic angle θ between phase a of the primary and phase a of the secondary is the angle in electrical radians relating mutual inductance between primary and secondary in the equation

$$M = M' \cos \theta$$

Substitute variables

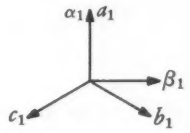
Symmetrical components is a method of substitute variables. In this method actual voltages and currents are replaced by suitably defined equivalent variables to simplify the analysis. The six transient equations of the form (1) are also simplified by the use of substitute variables.

The variables of the actual transient equations are per-phase voltage, current and flux linkages. Each varies sinusoidally with time. The symplification process has two steps:

1. A linear transformation is made converting the three-phase variables to a substitute two-phase set (right angle orientated). These substitute variables also vary sinusoidally with time.

2. An additional transformation is then made reducing the two-phase sinusoids to nonperiodic, direct and quadrature components.

The co-ordinate axis of the substitute alpha-beta variables is orientated with respect to the three-phase vector set of primary equations as shown in Figure 3.



Alpha axis current is linearly related to phase currents a, b and c by the equation

$$\frac{3}{2} i_{\alpha 1} = i_{a1} - \frac{1}{2} i_{b1} - \frac{1}{2} i_{c1} \qquad (3)$$

Equations of form (3) also relate alpha flux linkages and alpha applied voltage to phase variables a, b and c. The equation form for beta quantities in terms of beta currents is

$$\frac{3}{2} i\beta_1 = \frac{\sqrt{3}}{2} i_{b1} - \frac{\sqrt{3}}{2} i_{c1} \qquad (4)$$

Terminology

All constants and variables are as measured line to neutral, referred to the motor primary. If an armature is wound delta, all constants and variables are equivalent wye as measured line to neutral, referred to the motor primary. Subscripts a, b and c denote phase a, b or c.

Subscripts 1 and 2 indicate primary and secondary, respectively. Subscripts alpha and beta denote variable of the α—β, co-ordinate axis subscripts d and q indicate direct and quadrature components.

v = instantaneous applied voltage.

i = instantaneous current in amperes.

ψ = instantaneous total flux linkages in weber turns.

r = resistance in ohms.

p = operational notation for $\frac{d(\ )}{dt}$.

M' = maximum value of mutual inductance between one rotor phase and one stator phase in henrys.

M = mutual inductance in henrys.

m = magnetizing inductance $m = \frac{Xm}{2\pi f}$.

f = system frequency.

X_m = magnetizing reactance.

θ = magnetic angle between primary and secondary in electrical radians.

$p\theta$ = motor speed in electrical radians per second.

L_1 = apparent self-inductance of the primary

$$L_1 = \frac{X_1 + Xm}{2\pi f}.$$

X_1 = primary leakage reactance in ohms.

L_2 = apparent self-inductance of the secondary

$$= \frac{X_2 + Xm}{2\pi f}.$$

X_2 = secondary leakage reactance in ohms.

Phase quantities, for the primary equations, in terms of the alpha-beta variables are

$$M_{1a}$$

$$\begin{bmatrix} i_{a1} \\ i_{b1} \\ i_{c1} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & +\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \bullet \begin{bmatrix} i\alpha_1 \\ i\beta_1 \end{bmatrix}$$

$$M_{1b}$$

$$\begin{bmatrix} v_{a1} \\ v_{b1} \\ v_{c1} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & +\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \bullet \begin{bmatrix} v\alpha_1 \\ v\beta_1 \end{bmatrix}$$

$$M_{1c}$$

$$\begin{bmatrix} \psi_{a1} \\ \psi_{b1} \\ \psi_{c1} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & +\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \bullet \begin{bmatrix} \psi\alpha_1 \\ \psi\beta_1 \end{bmatrix}$$

The transformation matrix of the secondary variables in terms of current is

$$M_2$$

$$\begin{bmatrix} i_{a2} \\ i_{b2} \\ i_{c2} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ \cos(\theta+120°) & \sin(\theta+120°) \\ \cos(\theta-120°) & \sin(\theta-120°) \end{bmatrix} \bullet \begin{bmatrix} i\alpha_2 \\ i\beta_2 \end{bmatrix}$$

The same transformation applies to secondary voltage and flux linkages. If θ were zero, M_2 would equal M_1.

MATRIX IS SIMPLIFIED EQUATION FORM

$$i_{a1} = 0 + 1i\alpha_1$$

$$i_{b1} = -\tfrac{1}{2}\, i\alpha_1 + \frac{\sqrt{3}}{2} i\beta_1$$

$$i_{c1} = -\tfrac{1}{2}\, i\alpha_1 - \frac{\sqrt{3}}{2} i\beta_1$$

EXPRESS AS A MATRIX IS

$$\begin{bmatrix} i_{a1} \\ i_{b1} \\ i_{c1} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & +\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \bullet \begin{bmatrix} i\alpha_1 \\ i\beta_1 \end{bmatrix}$$

Alpha-beta equations

The motor's primary differential equations in alpha-beta form are

$$v\alpha_1 = r_1 i\alpha_1 + p\psi\alpha_1 \qquad (5)$$

$$v\beta_1 = r_1 i\beta_1 + p\psi\beta_1 \qquad (6)$$

These relationships are derived using Eqs. (1), (3), (4) and matrix M_1.

The motor's secondary equations in alpha-beta form are

$$v\alpha_2 = r_2 i\alpha_2 + p\psi\alpha_2 + \psi\beta_2\,(p\theta) \qquad (7)$$

$$v\beta_2 = r_2 i\beta_2 + p\psi\beta_2 - \psi\alpha_2\,(p\theta) \qquad (8)$$

The six equations needed to describe cage motor action have now been reduced to four. The number of variables has dropped from 18 to 12.

Flux linkages to machine constants

The total flux linkages of any particular phase (a, b or c) are the instantaneous sum of:

(1) The linkages due to self-inductance. (l_a l_b l_c)

(2) The linkages due to each of the neighboring phases on the same side of the air gap. (m_1)

(3) The linkages due to each of the three phases on the opposite side of the air gap.

$$\left[M' \cos\theta_1, M' \cos\left(\theta + \frac{2\pi}{3}\right), M' \cos\left(\theta - \frac{2\pi}{3}\right)\right]$$

The equations for the primary flux linkages of phases a, b and c are

$$M_3$$

$$\begin{bmatrix} \psi_{a1} \\ \psi_{b1} \\ \psi_{c1} \end{bmatrix} = \begin{bmatrix} l_a & m_1 & m_1 & M'\cos\theta & M'\cos\left(\theta+\frac{2\pi}{3}\right) & M'\cos\left(\theta-\frac{2\pi}{3}\right) \\ m_1 & l_b & m_1 & M'\cos\left(\theta-\frac{2\pi}{3}\right) & M'\cos\theta & M'\cos\left(\theta+\frac{2\pi}{3}\right) \\ m_1 & m_1 & l_c & M'\cos\left(\theta+\frac{2\pi}{3}\right) & M'\cos\left(\theta-\frac{2\pi}{3}\right) & M'\cos\theta \end{bmatrix} \bullet \begin{bmatrix} i_{a1} \\ i_{b1} \\ i_{c1} \\ i_{a2} \\ i_{b2} \\ i_{c2} \end{bmatrix}$$

Substituting M_2 and M_3 into

$$\psi\alpha_1 = \frac{2}{3}\left[\psi_{a1} - \frac{1}{2}(\psi_{b1}+\psi_{c1})\right] \qquad (9)$$

results in the following expression for primary alpha axis flux linkages:

$$\psi\alpha_1 = (l_1 - m_1)\, i\alpha_1 + \frac{3}{2} M'\, i\alpha_2 \qquad (10)$$

The quantity $(l_1 - m_1)$ is the apparent three-phase self-inductance of the motor primary armature winding (L_1). In terms of equivalent circuit constants, it is the sum of primary leakage and magnetizing reactance divided by 2π x frequency.

The constant $\frac{3}{2}M'$ is the apparent three-phase mutual inductance. Since all constants and variables are referred to the motor primary, $\frac{3}{2}M'$ is equal in magnitude to the magnetizing inductance. Its value is equal to magnetizing reactance divided by 2π x frequency.

Equation (10) can be rewritten as:

$$\psi\alpha_1 = L_1\, i\alpha_1 + mi\alpha_2 \qquad (11)$$

Substituting M_2 and M_3 into

$$\psi\beta_1 = \frac{1}{\sqrt{3}}(\psi_b - \psi_c) \qquad (12)$$

will give the equation for beta axis flux linkages.

$$\psi\beta_1 = L_1\, i\beta_1 + m\, i\beta_2 \qquad (13)$$

A similar process can be used to derive the expressions for secondary alpha and beta axis flux linkages.

$$\psi\alpha_2 = L_2 i\alpha_2 + m\, i\alpha_1 \qquad (14)$$

$$\psi\beta_2 = L_2\, i\beta_2 + mi\beta_1 \qquad (15)$$

If the flux linkage variables of Eqs. (5), (6), (7) and (8) are replaced with the linear relationships just derived, the following matrix results which completely describes the dynamic behavior of cage motor currents and flux.

M_4

$$\begin{bmatrix} v\alpha_1 \\ v\beta_1 \\ v\alpha_2 \\ v\beta_2 \end{bmatrix} = \begin{bmatrix} r_1+L_1p & 0 & mp & 0 \\ 0 & r_1+L_1p & 0 & mp \\ mp & m(p\theta) & r_2+L_2p & L_2(p\theta) \\ -m(p\theta) & mp & -L_2(p\theta) & r_2+L_2p \end{bmatrix} \bullet \begin{bmatrix} i\alpha_1 \\ i\beta_1 \\ i\alpha_2 \\ i\beta_2 \end{bmatrix}$$

The electromagnetic force (F) developed between two magnetically coupled electric circuits is

$$F = i_1\, i_2 \frac{dM}{dX} \qquad \text{newtons} \qquad (16)$$

where m = mutual inductance in henrys and dX = virtual displacement in meters.

The rotational equivalent of Eq. (16) for an induction motor is

$$\text{Torque} = i_{\text{stator}}\ i_{\text{rotor}} \frac{dM}{d\theta} \quad \text{newton meters} \qquad (17)$$

Expanding Eq. (17) into its three-phase form yields

$$T = M' \frac{\text{poles}}{2}\begin{bmatrix} (i_{a1}i_{a2}+i_{b1}i_{b2}+i_{c1}i_{c2})\ \sin\theta \\ (i_{a1}i_{b2}+i_{b1}i_{c2}+i_{c1}i_{a2})\ \sin\left(\theta+\frac{2\pi}{3}\right) \\ (i_{a1}i_{c2}+i_{b1}i_{a2}+i_{c1}i_{b2})\ \sin\left(\theta-\frac{2\pi}{3}\right) \end{bmatrix} \qquad (18)$$

The expression for torque in terms of the alpha-beta components is derived using matrix M_{1a} *and* M_2 in Eq. (18).

$$T = \frac{-3}{2} m \frac{\text{poles}}{2}(i\beta_1\, i\alpha_2 - i\alpha_1\, i\beta_2) \text{ x } (.738) \text{ (lb-ft)} \qquad (19)$$

Matrix M_4 and Eq. (19) completely describe the transient and steady-state behavior of a three-phase induction motor. However, the variables of this treatment are sinusoidal and as such are not in optimum form for an analog solution.

Direct and quadrature components eliminate sinusoidal functions

Each sinusoidal alpha variable can be expanded to a set of equivalent direct and quadrature (D-Q) components with the following trigonometric identity.

$$\begin{aligned} v\alpha &= V_d \cos wt - Vq \sin wt \\ i\alpha &= I_d \cos wt - Iq \sin wt \end{aligned} \qquad (20)$$

And each sinusoidally varying beta variable can be expanded to a set of equivalent direct and quadrature components with the equation

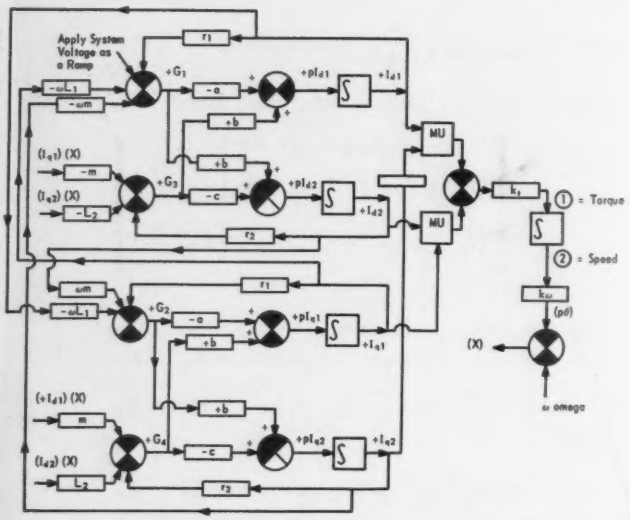
$$\begin{aligned} v\beta &= V_d \sin wt + Vq \cos wt \\ i\beta &= I_d \sin wt + Iq \cos wt \end{aligned} \qquad (21)$$

The above transformation applies to the voltage and current variables of both the primary and secondary windings.

When identities (20) and (21) are substituted into M_4, two sets of equations are obtained. The D-Q variables of one set are all functions of cos wt, whereas those of the other are functions of sin wt. Since the air gap is uniform, the phenomena in the cos wt axis are identical to that in the sin wt axis. Thus either set may be selected and equated to zero for a complete solution. The resulting matrix in terms of direct and quadrature components is:

M_5

$$\begin{bmatrix} E_d \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} r_1+L_1p & -\omega L_1 & +mp & -\omega m \\ +\omega L_1 & r_1+L_1p & +\omega m & +mp \\ +mp & -m(\omega-p\theta) & r_2+L_2p & -L_2(\omega-p\theta) \\ m(\omega-p\theta) & mp & L_2(\omega-p\theta) & r_2+L_2p \end{bmatrix} \bullet \begin{bmatrix} I_{d1} \\ I_{q1} \\ I_{d2} \\ I_{q2} \end{bmatrix}$$



DIFFERENTIAL EQUATIONS are solved on a digital computer using a dynamic block diagram.

The substitution of identities (20) and (21) into Eq. (18) yields the following expression for motor torque in D-Q components.

$$T = \frac{-3}{2} m \frac{\text{poles}}{2} (.738) \left[(I_{d1} I_{q2} - I_{q1} I_{d2}) \right] \text{lb-ft} \qquad (21)$$

The solution of M_5 and Eq. (21) on the analog computer involves the subtraction of large variables and the amplification of their difference. Thus optimum magnitude scaling and four place computer accuracy are necessary for satisfactory results. In some cases, per unit coefficients will simplify the magnitude scaling problem. In addition, one-tenth time scaling is often used to reduce integrator gain relating the variable to its rate of change with time. The analog circuit of M_5 graphically illustrates the presence of a redundancy in the pI_d and pI_q terms.

If pI_{d1}, pI_{d2}, pI_{q1}, and pI_{q2} of M_5 are selected as the dependent variables, a determinant solution using I_{d1}, I_{d2}, I_{q1} and I_{q2} as the independent variables will eliminate the equation redundancy and also the algebraic loop of the analog circuit. The final equations completely describing cage motor action are:

$$pI_{d1} = bG_3\text{-}aG_1 \qquad pI_{q1} = bG_4\text{-}aG_2$$
$$pI_{d2} = bG_1\text{-}cG_3 \qquad pI_{q2} = bG_2\text{-}cG_4$$

where

$$\begin{bmatrix} G_1+E_{d1} \\ G_2 \\ G_3 \\ G_4 \end{bmatrix} = \begin{bmatrix} +r_1 & -\omega L_1 & 0 & -\omega m \\ +\omega L_1 & +r_1 & +\omega m & 0 \\ 0 & -m(\omega-p\theta) & +r_2 & -L_2(\omega-p\theta) \\ +m(\omega-p\theta) & 0 & L_2(\omega-p\theta) & +r_2 \end{bmatrix} \bullet \begin{bmatrix} I_{d1} \\ I_{q1} \\ I_{d2} \\ I_{q2} \end{bmatrix}$$

CO-ORDINATE AXIS VALUES

$$Va = \text{line-to-line volts} / \sqrt{3}$$
$$v\alpha_1 = \sqrt{2}\, V_a \cos wt$$
$$v\beta_1 = \sqrt{2} V_a \sin wt$$
$$E_{d1} = \sqrt{2} V_a$$
$$a = \frac{L_2}{L_1 L_2 - m^2}$$
$$b = \frac{m}{L_1 L_2 - m^2}$$
$$c = \frac{L_1}{L_1 L_2 - m^2}$$

Induction motor equations aid in system studies

The chief application of this cage motor representation is in areas where large changes in torque and speed are expected because of an external disturbance. Once M_5 and Eq. (22) or M_6 and Eq. (23) have been programmed on either the digital or analog, any number of disturbances can be added and their effects on cage motor performance studied.

The only constants needed for matrix equations M_5 and M_6 are X_1, X_2, r_1, r_2, and X_m. Normally these are the "running hot" values. The constants for the mechanical equations (not derived) are motor and load inertia and load torque as a function of speed. With this basic data problems involving induction motor transient characteristics can be studied.

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2. *Advanced Calculus*, Wilford Kaplan, Addison Wesley Publishing Co. Inc., 1952.

DIGITAL COMPUTER provides an accurate method of solving induction motor equations.

Evaluating LOAD TAP-CHANGER CIRCUITS

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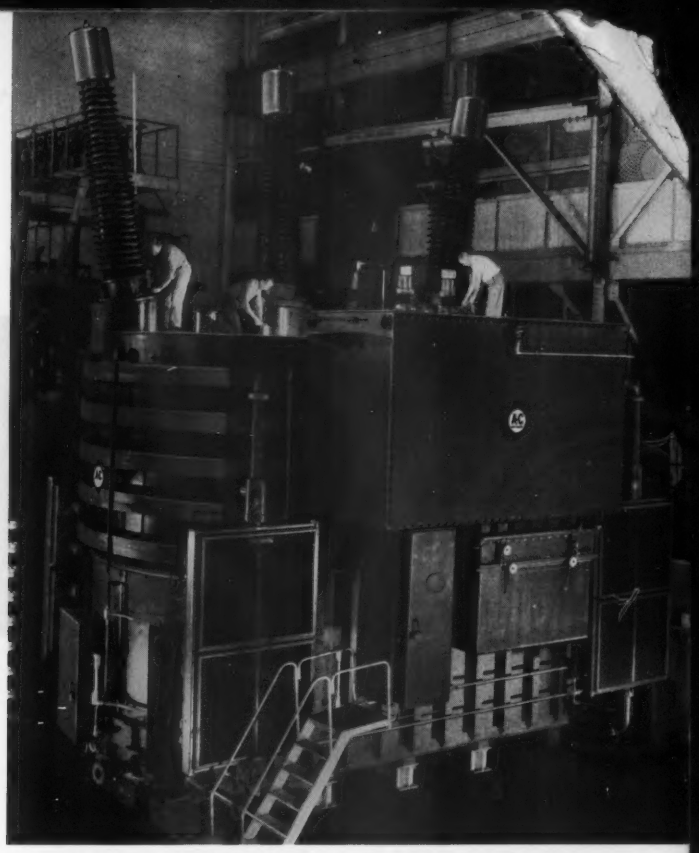


LOAD TAP-CHANGER circuits are selected to fit application. This 100,000-kva, 330-kv transformer utilizes a reversing switch to obtain plus or minus 10 percent voltage range in 32 steps.

Application of load tap changers is aided by proper circuit and component selection.

LOAD TAP-CHANGING transformers are being built in a wide range of kva ratings, voltages and currents. As a result, numerous LTC mechanisms have been developed, each having a given current rating and corresponding voltage rating. The rating may be expressed as a curve, shown in Figure 1.

The duty of a mechanism can be reduced by suitable selection of a tap-changer circuit. Longer mechanism life and a lower cost of maintaining constant voltage can be obtained.

A simple application of a nine-contact mechanism to a transformer winding is shown in Figure 2. This application, using the half cycling positions, results in 17 positions and 16 steps for the load tap changer, and a total range in voltage from minimum to maximum of 8 *E* at a line current of *I* amperes.

When a given mechanism is applied to a single-phase transformer for a 10 percent range in taps at constant current, the transformer kva is equal to 10 times the tap-changer kva range, or for a three-phase transformer 30 times the tap-changer kva range. The kva for each physical tap is equal to *EI*. With 8 physical steps, the range is equal to 8 *EI* and the maximum transformer kva is equal to 240 *EI*.

Reversing switches provide more steps

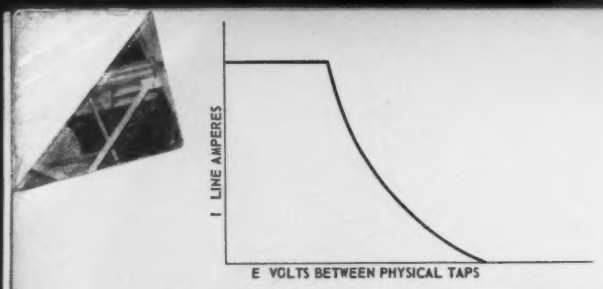
The most common application of LTC mechanisms is to produce 10 percent buck or boost in voltage in 32 steps. This is accomplished by using a reversing switch in connection with a 9-point dial switch so that each contact is used twice, once when the reversing switch is in "raise" position and again when the reversing switch is in the "lower" position.

By the use of reversing switches, such as shown at *R* in Figures 3 and 4, the number of steps and the voltage range may be doubled, resulting in 33 positions, 32 steps and a total range in voltage of 16 *E* at a line current of *I* amperes. When moving contacts *A* and *B* are on stationary contact *O*, the reversing switch *R* may be moved between *N* and *M* at no current in the switch. In each switch, when *C* is connected to *M*, the effective winding turns are increased. When *C* is connected to *N*, the effective winding turns are decreased. The arrangement of Figure 3 is used for autotransformer feeder voltage regulators, while that of Figure 4 is often used for power transformers.

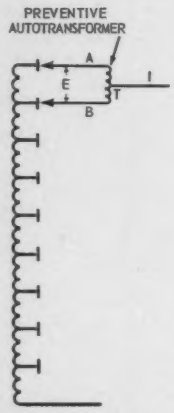
When a given mechanism is applied to a three-phase transformer for ± 10 percent range in taps at constant current, a three-phase transformer rating of 15 times the tap-changer kva range is obtained. For this example the maximum transformer volt-amperes are equal to 240 *EI*.

Auxiliary windings help

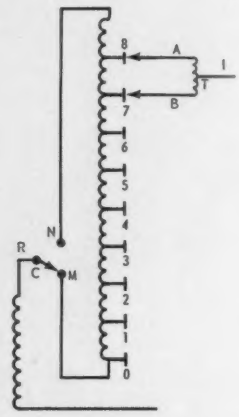
The transition voltage at the arcing contacts during a tap change can be reduced to half value by connecting wind-



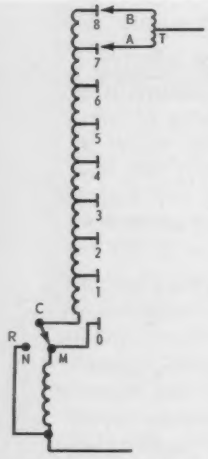
TYPICAL performance curves for load tap-changer mechanism give current for given voltage between taps. **(FIGURE 1)**



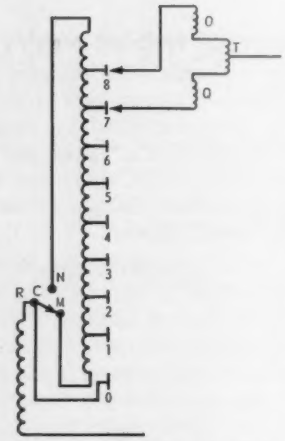
PREVENTIVE autotransformer is used with 16-step unit. **(FIG. 2)**



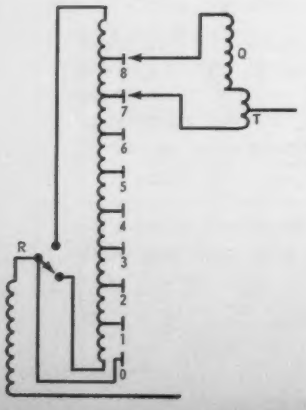
REGULATOR-type reversing switch provides 32 steps. **(FIGURE 3)**



TRANSFORMER-type reversing switch also gives 32 steps. **(FIG. 4)**



TWO auxiliary windings are used on main transformer core. **(FIG. 5)**



ONE auxiliary winding is used on main transformer core. **(FIGURE 6)**

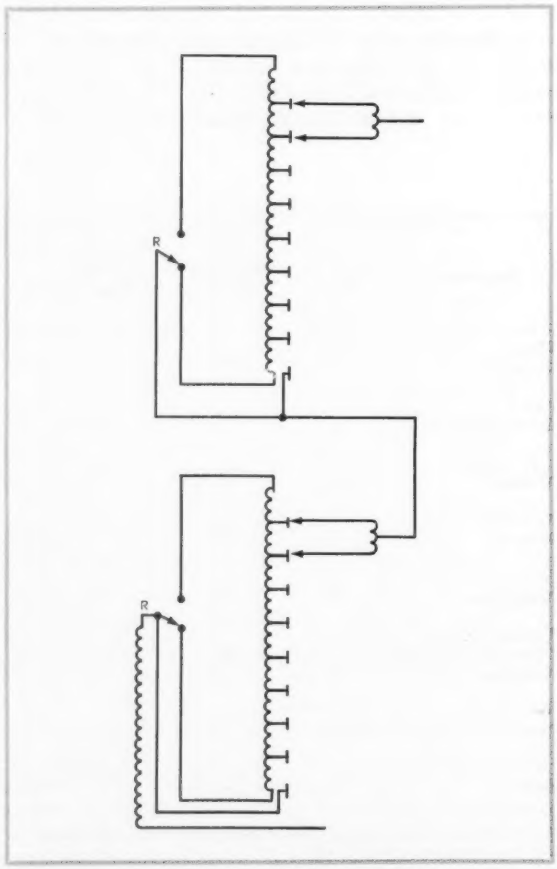
ings Q in the circuit, as shown in Figures 5 or 6. The Q coils are placed on the core of the main transformer, making the voltage of each Q coil equal to 0.25 E, Figure 5 or 0.5 E, Figure 6. This change effectively doubles the voltage range to 32 E and the transformer volt-amperes to 480 EI.

By placing two tap-changing mechanisms in series, with each operating independently, as shown in Figure 7, the number of taps and voltage range can be doubled. For the same voltage range, this also doubles the permissible volt-ampere rating of the transformer, increasing it to 960 EI.

Where the kva is within the limitations of the mechanism but either the current or voltage limits are exceeded, series transformers are often used, as shown in Figure 8. They provide selection of voltage and current for the mechanism within its normal range. In the table, P is the ratio of the line turns to the LTC turns of the series transformer. Where the voltage of the main winding is higher than the voltage rating of the mechanism, a separate winding may be used for the tap-changer circuit to isolate it from the main winding.

Mechanisms may be paralleled

Current rating of 200 percent of the usual rating can be obtained by using two separate tap-changing mechanisms and operating them in parallel, as shown in Figure 9. A



TWO LOAD TAP CHANGERS in series double the range of voltage regulation available from the transformer. **(FIGURE 7)**

balance coil D forces the current to divide equally between the two mechanisms. In order to limit the maximum voltage which can appear across D, common practice is to interlock the two mechanisms mechanically.

Using two mechanisms in this way doubles the volt-ampere rating and the current rating of the combination.

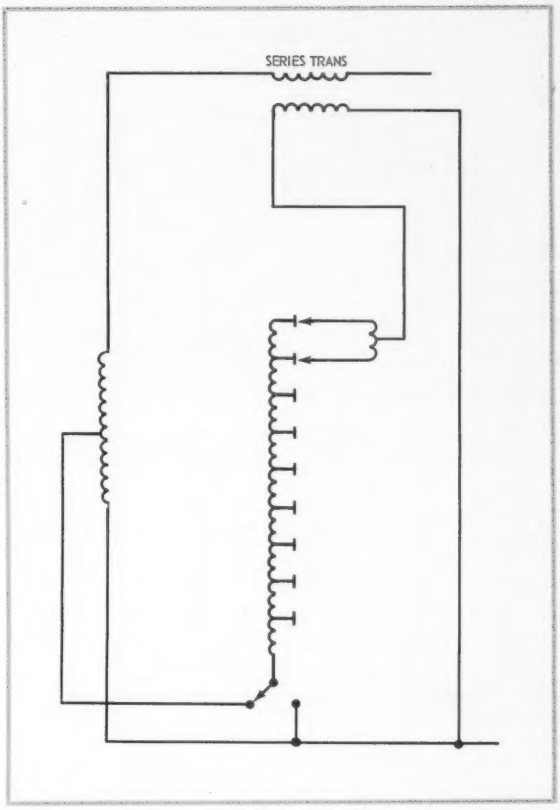
Range is extended with additional switches

If no-load switches are used, as shown in Figure 10, the circuit is similar to the simple reversing switch of Figures 3 and 4. With this arrangement the voltage range for a mechanism can be increased several times. The number of voltages is correspondingly increased.

In Figure 10 windings 1 to 8 and 11 to 16 are on the main core. The load tap changer has moving contacts A and B connecting to leads 0 to 8. There are two no-load auxiliary switches. In one S connects moving contact 0 to stationary contacts 11 to 16. The other auxiliary switch has a moving contact R which connects R to stationary contacts 11 to 15. It moves only when A and B are on contact 0. Moving contact S moves only when A and B are not on 0.

Voltages from 0 to E_1 are obtained when R is connected to 11 and S is connected to 11 or 12.

With S connected to 12 and A and B on 0, contact R is moved to connect to 12. Voltages from E_1 to $2E_1$ are obtained as the LTC moves through 1 to 8. Contacts 0 to 8 are placed on a circular dial switch which moves in the same direction while the line voltage is increased from 0 to $5E_1$ for the arrangement shown in Figure 10. A large number of steps and greater range can be obtained by increasing the main tapped winding and the number of con-

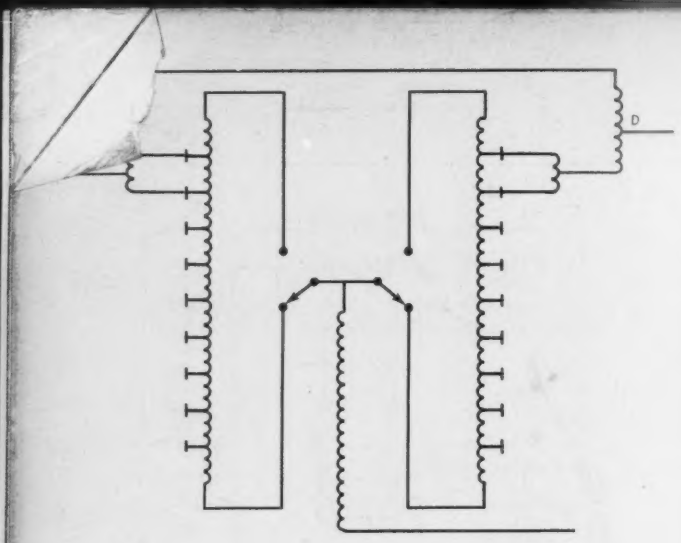


SERIES TRANSFORMERS are often used for certain voltage or current requirements within the changer kva rating. **(FIGURE 8)**

TABLE I

Description	Fig. No.	Reversing Switch	Auxiliary Winding	Other Data	Total Voltage Range	Current	Total Voltage Range In Percent of Transformer Voltage Rating	Three-Phase Transformer Kva When EI = 10 Kva
Simple Connection	2	—	—		8 E	I	10	2400
Add Reversing Switch	3 4	Yes	—		16 E	I	20	2400
Add Auxiliary Winding	5 6	Yes	Yes		32 E	I	20	4800
Two Mechanisms In Series	7	Yes	Yes		64 E	I	20	9600
Series Transformer	8	Yes	Yes		32 EP	$\frac{I}{P}$	20	4800
Reduced Exciting Current of Preventive Autotransformer	5 6	Yes	Yes		25 E	1.3 I	20	4800
Two Mechanisms In Parallel	9	Yes	Yes		32 E	2 I	20	9600
With No Load Switches	10	Special No Load Switches	Yes	4 tapped sections 10 tapped sections	64 E 160 E	I I	20 100	9600 4800

E is the rated voltage between physical taps for the simple connection.
I is the corresponding line current.
P is the ratio of line turns to the LTC turns of the series transformer.



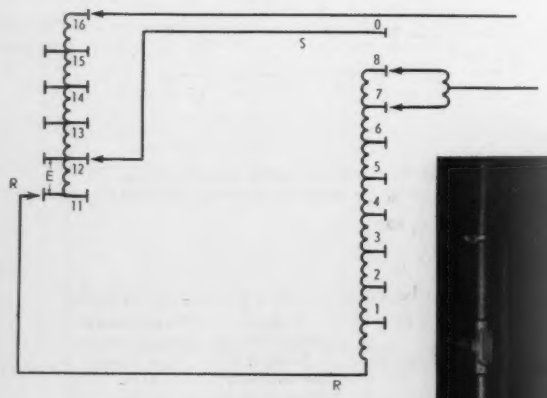
CURRENT rating of 200 percent can be obtained when two separate tap changers are connected in parallel. **(FIG. 9)**

tacts on the auxiliary switches. A total range in voltage of 80 *E* would result from 10 tapped sections. If auxiliary windings are used, a voltage range of 160 *E* at a current *I* is obtainable.

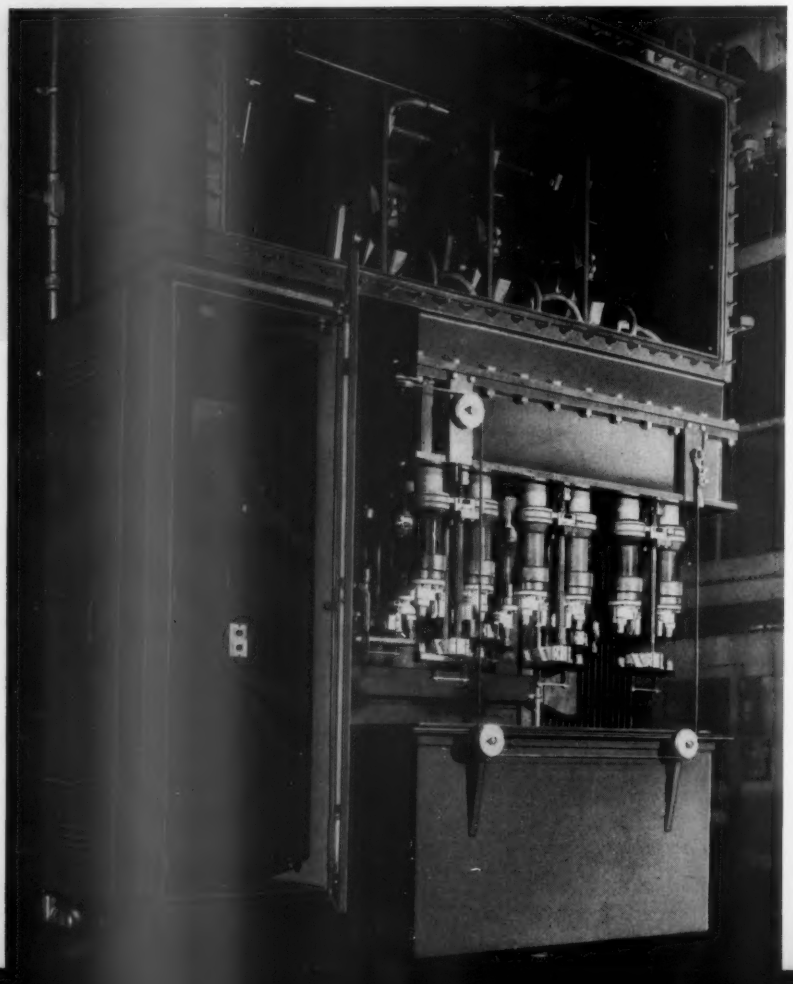
An application for 10 tapped sections is for a voltage range equal to 100 percent of line voltage.

Four tapped sections could be used to double the permissible voltage range for a 20 percent total tap range in voltage.

The results listed in Table I may be used for a comparison of the various arrangements. The last column shows the resulting transformer kva when $EI = 10{,}000$ volt-amperes or 10 kva. For other values of *EI*, the kva's are proportional. Other combinations of the connections are possible, such as three mechanisms in series or parallel, use of auxiliary windings with the simple connection of Figure 2, use of reduced exciting current with any connection. The various alternatives show how the capabilities of a mechanism can be more fully utilized.

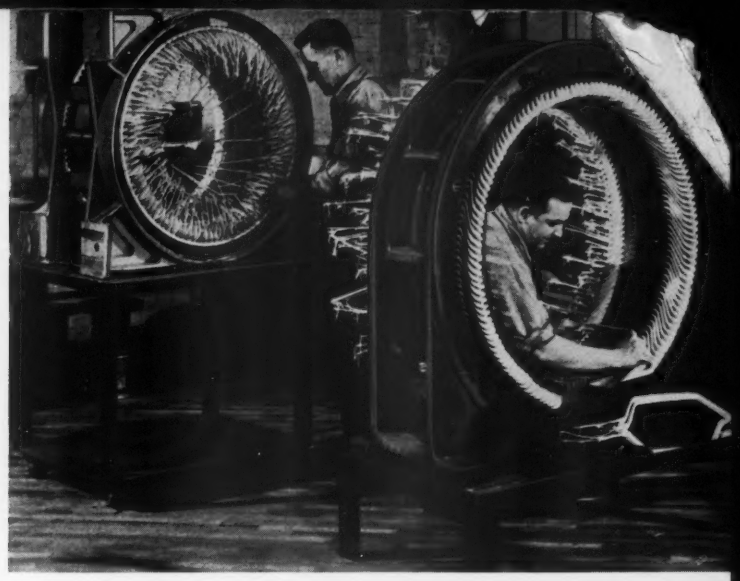


MULTI-CONTACT auxiliary switch may be used to extend the voltage range of a mechanism several times. **(FIG. 10)**



HEAVY-DUTY load tap-changing mechanisms of this type are capable of handling load tap changers for transformers up to 1,300,000 kva, when suitable circuits are selected.

Short Cut
IN GROUPING BALANCED THREE-PHASE FRACTIONAL-SLOT WINDINGS



COIL WINDERS must know the proper coil grouping of a balanced fractional-slot stator before the internal connections can be made.

by G. R. BROOKS
Motor-Generator Dept.
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Simplified method of selecting coil grouping for fractional-slot windings is helpful when rewinding a motor for different pole arrangements.

FRACTIONAL-SLOT WINDINGS are the most common type found in synchronous machines. They can also be used on many induction machines when it becomes necessary to rewind for different speeds. How winding problems are solved will add to an understanding of how machines are built.

Sometimes the number of slots on the motor is such that an integral-slot winding is possible for the desired new number of poles, but usually a fractional-slot winding will be required. Fractional-slot windings for induction and synchronous machines have a non-integral number of slots per pole per phase.

Advantages of balanced fractional-slot windings are wider use of an established slotting, reduction of certain harmonics in the air-gap flux or terminal voltage, and an improved distribution factor. While in some instances there are possible disadvantages, such as undesirable noise or vibration, many induction motors and most synchronous machines successfully employ this type of winding.

Several methods may be used to determine the proper unequal coil grouping associated with a given slotting, only three-phase arrangements being considered.

(a) A balanced three-phase fractional-slot winding is possible if the total number of slots is divisible by the factor *F* corresponding to a given number of poles as shown in Table I.

(b) The total number of slots must also be divisible by three times the number of parallel circuits contemplated. This is for the widely used 60-degree phase belt connection.

Unequal grouping is usually expressed as a series of numbers each of which represents the number of coils in a pole-phase group in the order of their placement around the periphery of the winding. A balanced fractional-slot winding for a six-pole motor with 81 slots would therefore have its coil grouping expressed as:

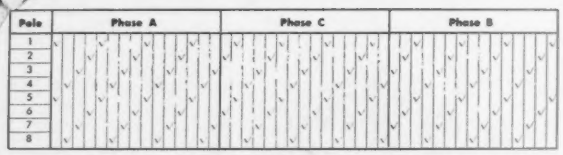
454, 545, 454, 545, 454, 545.

The grouping can be analyzed as follows: The sum of the above numbers is 81, which is equal to the total number of slots. The first three numbers represent the three-phase groups of the first pole, and each subsequent three numbers represent the three-phase groups of each subsequent pole. Thus poles 1, 2, 3, 4, 5, and 6 have 13, 14, 13, 14, 13, and 14 coils each, respectively. Phase *A* has four

TABLE I. F as a function of the number of poles.

No. of Poles	F	No. of Poles	F
2	3	26	3
4	3	28	3
6	9	30	9
8	3	32	3
10	3	34	3
12	9	36	27
14	3	38	3
16	3	40	3
18	27	42	9
20	3	44	3
22	3	46	3
24	9	48	9

Pole	1	2	3	4	5	6
Phase Group	A C′ B	A′ C B′	A C′ B	A′ C B′	A C′ B	A′ C B′
No. of Coils Per Group	4 5 4	5 4 5	4 5 4	5 4 5	4 5 4	5 4 5



Check Chart

coils from pole No. 1 connected in series with five coils of pole No. 2, and so forth. This can be shown below in more detail, the prime indicating a reversed connection.

Since the factor *F* for six poles is 9 and 81 slots is divisible by 9, the winding will balance. Also 81 slots must be divisible by three times the number of circuits, so the only possible numbers of circuits in this case are 1 and 3. The phase group symbolism shown is for the well-known 60-degree phase belt type of connection.

There are several well-known ways to arrive at a proper grouping for a three-phase balanced fractional-slot winding. However, most methods in use are rather cumbersome.

There is the old cut-and-try method whereby the number of slots per pole per phase is approximated by holding to a minimum the difference between the calculated fractional value and the nearest integral number as progress is made around the winding. A check is then made for balance and sometimes considerable juggling is necessary before balance is established.

The check chart system is also in use. Setting up this chart involves a least common multiple of two numbers, one being the number of slots, the other being the product of the number of poles and number of phases. The width of the chart is this least common multiple divided by the number of poles, and the depth of the chart is equal to the number of poles, with equal rectangular spaces being used as units. When counting off these spaces from left to right, the number of spaces representing one coil is equal to the least common multiple divided by the number of slots. The chart is divided from right to left into three equal widths to represent the three phases. A check mark is first made in the upper left-hand corner space on the chart, then check marks are continued in a left to right, down, left to right, down, and so on, reading style pattern. Check marks are thus entered, one for each group of spaces representing one coil. This pattern is continued until it runs out at the bottom right of the chart.

EXAMPLE: Suppose it is desired to rewind an existing ten-pole, three-phase motor having 90 total slots. Will the winding balance and what will the grouping be if we rewind this motor for eight poles instead of ten poles? How many circuits are possible?

F for eight poles = 3; 90 slots is divisible by 3, so the winding will balance. The factors of eight poles are 1, 2, 4 and 8. These are the possible numbers of circuits for an integral-slot winding. However, 90 slots must be divisible by 3 times the number of circuits for a fractional-slot winding. Therefore, only 1 and 2 circuits are possible.

Number of slots $= 90 = 3 \times 30 = 3 \times 3 \times 10 = 3 \times 3 \times 5 \times 2$

Poles x phases $= 8 \times 3 = 24 = 3 \times 2 \times 2 \times 2$

Least common Multiple $3 \times 3 \times 5 \times 2 \times 2 \times 2 = 360$

Chart width $= 360 \div 8 = 45$ spaces

Phase width $= 45 \div 3 = 15$ spaces

Slot width $= 360 \div 90 = 4$ spaces

Collecting the check marks in a reading pattern results in the following grouping:

444, 344, 434, 443, 444, 344, 434, 443

Note that the pattern of check marks and grouping repeats every four poles, confirming that a two-circuit winding is possible.

This example serves to show how cumbersome the chart system is. The chart system is used to avoid the pitfalls of the cut-and-try method which can be even more troublesome for some slottings.

A short-cut method will show the grouping pattern with less work.

Again consider the example used to show the check chart system.

90 slots, eight poles, three phases

$$\frac{\text{Slots/Pole}}{\text{Phase}} = \frac{90}{8 \times 3} = 3\tfrac{3}{4}$$

(1) $3\frac{3}{4} = 15/4$ (3) $4\frac{1}{4} = 17/4$

(2) $4\frac{2}{4} = 18/4$ (4) $4 \quad = 16/4$

(1) Write the slots per pole per phase as a mixed number equating to its improper fraction as shown.

(2) Add the 3 from the $\frac{3}{4}$ to the 15 and write $18/4$. Equate back to $4\frac{2}{4}$ as shown.

(3) Add the 2 from the $\frac{2}{4}$ to the 15 and write $17/4$. Equate back to $4\frac{1}{4}$ as shown.

(4) Add the 1 from the $\frac{1}{4}$ to the 15 and write $16/4$. Equate back to 4 as shown. Since 4 is an integer we stop here. Writing the whole parts of the mixed numbers in reverse order we have 4 4 4 3.

Carrying this on to make eight poles we have

444, 344, 434, 443, 444, 344, 434, 443

which is the same result as with the check chart system.

This method will always apply in like manner for any three-phase balanced winding having a fractional number of slots per pole per phase.

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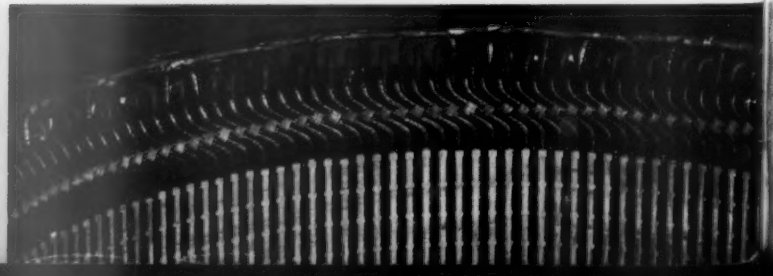
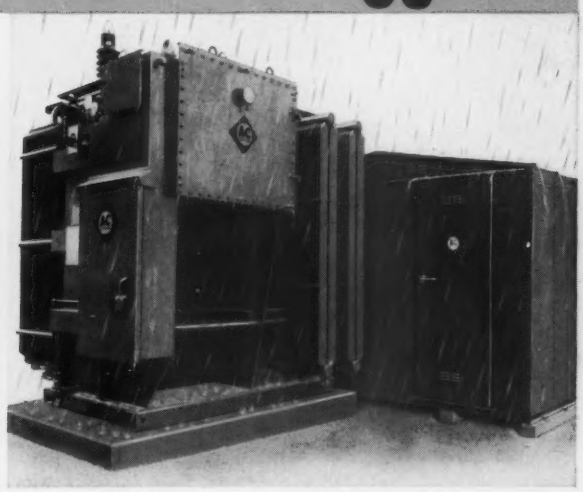
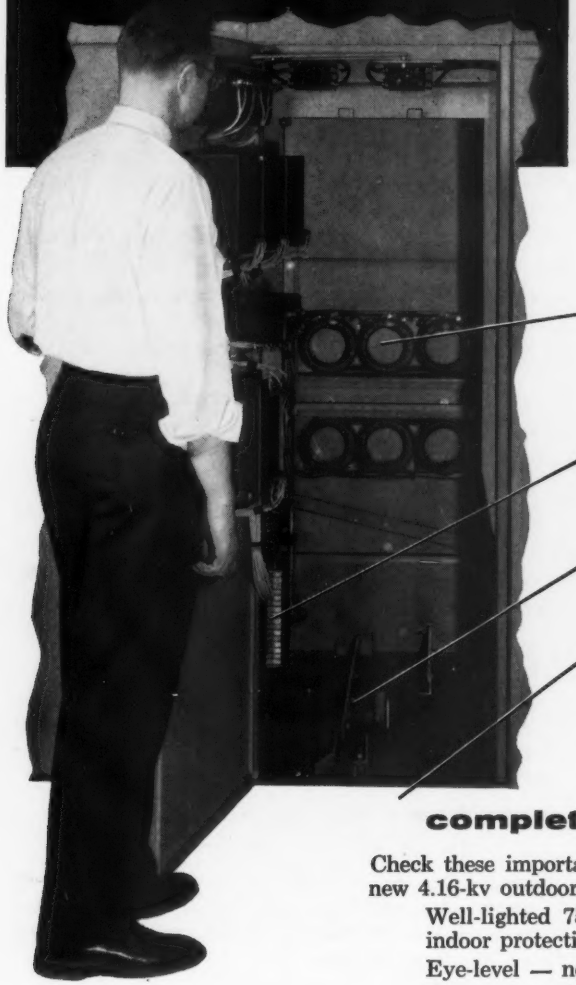


COIL GROUPING of 323, 232, 323, 223, 232, 323, 232, 232, 323, 232, 322, repeats every 11 poles; therefore a two-circuit winding is possible.

ALLIS-CHALMERS modern line for '59





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Kit provides materials and instruction for field-testing transformer oil.

RESEARCH

SOLVES OIL TEST PROBLEM

TWO NEWLY DEVELOPED, quick and simple tests now make it possible to measure acidity and polar contamination of transformer and regulator oil in the field. Acid and polar compounds are formed in the oil during service and eventually an insoluble sludge accumulates on cooling surfaces, interfering with efficient cooling.

Although laboratory tests are recommended for thorough analysis, costs and delays in handling samples and awaiting laboratory reports have made a quicker method desirable. The new field tests provide a rapid check to determine if the oil is still serviceable, or if laboratory tests are required. While long service life can be expected from transformer oil, these new tests will allow the user to check the oil condition regularly. Fewer laboratory analyses will be necessary.

An acidity test indicates whether or not the acid content of the oil falls within an acceptable range. Acid ratings are obtained through comparison of an indicator spot with a color chart. Acidity is not troublesome from the standpoint of corrosion, but serves as a measure of oil aging.

The second test provides a direct measure of the polar compound content of the oil. The general term "polar compounds" is applied to a series of materials often present in oils as a result of oxidation. In this test the shape of a red indicator spot serves as a measure of polar contamination.

If an oil sample has low acidity and low polar contamination as determined by the spot tests, sludge formation is not apt to be of immediate concern. However, if either test indicates that the oil is unsatisfactory, the sample should be submitted to a laboratory.

by **R. E. REINHARD**
Chemical Services Section
Research Laboratories
Allis-Chalmers Mfg. Co.